LABORATORY EXERCISES

IN

BOTANY

DESIGNED FOR THE USE OF

COLLEGES AND OTHER SCHOOLS IN WHICH BOTANY
IS TAUGHT BY LABORATORY METHODS

BY

EDSON S. BASTIN, A. M.

PROFESSOR OF MATERIA MEDICA AND BOTANY AND DIRECTOR OF THE MICROSCOPICAL
LABORATORY IN THE PHILADELPHIA COLLEGE OF PHARMACY.

ILLUSTRATED WITH 7 FIGURES IN THE TEXT,
AND 87 FULL-PAGE PLATES FROM ORIGINAL DRAWINGS,
COMPRISING UPWARD OF 250 FIGURES.

PHILADELPHIA
W. B. SAUNDERS
925 WALNUT STREET.
1895.

George B. Torr
Boston

ELECTROTYPED BY
WESTCOTT & THOMSON, PHILADA.

PRESS OF
W. B. SAUNDERS, PHILADA.

PREFACE.

THIS book has had its birth in the laboratory. It embodies methods that have been evolved during many years of observation and experience in conducting a botanical laboratory for students of pharmacy. It aims to inculcate in the student, by the study of properly-selected examples, a knowledge of the elementary principles of botany, to develop his observing faculties, to stimulate in him the spirit of investigation, and to lead him to take delight in a beautiful science.

While the course here laid down is strictly an elementary one, and aims to cover only a small part of a wide and interesting field, an effort has been made in the selection and arrangement of themes to lay a sound foundation for the pursuit of the more difficult branches of the science. The intelligent student who has completed the course in a thorough manner may not yet be a botanist, but he will have acquired both the methods and the spirit that fit him for original work in the science.

Two things have been kept steadily in view in the preparation of the book: the needs of private students pursuing botany without the aid of a teacher, and the requirements of such schools and colleges as have cast aside the old text-book methods of worrying the students with botanical hard names, and have adopted natural methods of teaching botany. It is believed that the illustrations of plant-structure that accompany each exercise—all of which were drawn by the author from natural objects, and were reproduced for the book by photographic process—will greatly smooth

the way for the private student, and also be of considerable service both to teachers and classes in the college laboratory.

The book is written in two parts, the first dealing chiefly with the gross structure of flowering plants, or that which may be observed with no further aid than that of a simple microscope, and the second devoted chiefly to the microscopic structure of plants. The plan pursued is similar in all the exercises. Each is a study, made direct from Nature, of some plant, plant-organ, tissue, or product, and the student is expected first of all to verify the descriptions and drawings by observations of his own, and then to make independently one or more parallel studies of some similar object or objects selected from the list given in the exercise.

It has not been deemed wise to cumber the book with numerous descriptions of processes and methods, but there have been given only the most useful and those whose value has been well proved by experience. While, also, the list of apparatus, reagents, stains, and mounting media might have been lengthened very materially, it is thought to include all the essentials for an elementary course, and to be therefore of more practical value, and less confusing to beginners, than a more extended list.

For many of the formulæ for the preparation of reagents and stains, and for some processes, the author acknowledges his indebtedness to the admirable books of E. Strasburger, A. Zimmermann, and Arthur Bolles Lee.

EDSON S. BASTIN.

PHILADELPHIA, Sept. 15, 1894.

CONTENTS.

PART II.—VEGETABLE HISTOLOGY.

LABORATORY EXERCISES IN BOTANY.

GENERAL INTRODUCTION.

THIS work is divided into two parts: the first, which is intended for beginners, requires no optical appliances for its successful study save the simple microscope. It deals mainly with the gross structure of flowering plants, and includes the study of roots, ordinary stems, rhizomes, tubers, corms, bulbs, leaves, flowers, fruits, and seeds. The second part, which is intended for students somewhat more advanced, requires the use of the compound microscope. It is devoted mainly to the study of the microscopic structure of the various organs of flowering plants.

Each exercise is a study as faithful and as accurate in its descriptions and drawings as the author could make it of some portion of the plant-structure. It is expected that the student will, first, verify the facts stated and illustrated in the exercise by observations of his own, made according to directions, and then make an independent but parallel study from some one or more of the other plants named at the opening of the exercise. In doing this he should by no means neglect the drawings. They are useful not only in explaining to others the structures observed, but they are themselves great aids also to accurate observation, and are equally helpful in giving vividness and permanency to knowledge. A structure that has once been understood thoroughly, and has been accurately drawn, makes a lasting impression upon the mind. The drawing need not be elaborate, the time-consuming work of shading may often be omitted; but no pains should be spared to make it accurate, and all drawings for scientific purposes should be made to a definite scale.

It is hardly necessary that the student should have had any previous instruction in botany to pursue this course successfully, though the previous perusal of Parts I. and II. of the author's *College Botany*, or of some other book covering similar ground,

would be of advantage. Such a book, however, should be constantly on hand during laboratory-work for reference.

The glossary in the book above referred to will also be of service, for while these exercises are not, it is hoped, overburdened with technical terms, it has not been thought wise to omit them altogether. If botany is mastered, its language must also be acquired.

PART I.

ORGANOGRAPHY.

INTRODUCTION.

THE equipment required by the student to pursue the course of study here laid down is simple and inexpensive. A good magnifying-glass, a pair of dissecting needles, a sharp pocket-knife or a scalpel, six glass slides and twice as many cover-glasses for temporarily mounting sections, a camel's-hair brush of medium size, a rule with the metric scale on one edge, a pair of delicate forceps, with drawing- and memorandum-books and pencils for keeping the appropriate records of observations made, are all that are really necessary.

It would be a great advantage, however, if the student were to get, in place of the ordinary pocket-magnifier, a good dissecting microscope, so that he may have both hands free for the work of dissection. Efficient instruments of this kind are easily obtainable at a moderate cost from many different manufacturers and dealers. The instrument shown in the accompanying cut is both

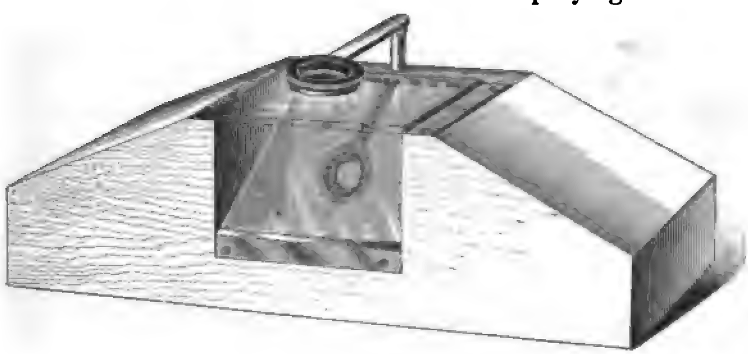


FIG. 1—Dissecting Microscope.

efficient and inexpensive. The body consists of a solid block of hard wood so shaped that the sides serve as hand-rests. The

stage is of glass, below which is a mirror, fixed at an angle of 45° for the illumination of a transparent object on the stage, and there is a square rubber plate, one side of which is white and the other black, to insert between the mirror and the stage whenever white- or dark-ground illumination is required. The metallic lens-holder slides in a brass tube driven into a hole in the back of the block, into which the cylindrical column of the holder nicely fits, rendering the lenses easily adjustable for focus. The instrument is provided with two lenses, which may be used singly or in combination, giving a range of powers of from five to fifteen diameters.

The reagents employed are also few and easily prepared, and are as follows:

Iodine Solution.—This solution is thus prepared: Saturate a small quantity of distilled water with potassium iodide, and then dissolve in it all the iodine crystals the solution will take up, and dilute with distilled water until the liquid has a deep wine color. This solution stains proteid matters yellowish-brown, lignified tissues a deep brown, cellulose tissues scarcely at all, and starch-grains a deep blue. In using the solution as a test for starch in sections it is best to dilute it with four or five times its bulk of water, otherwise the grains will be so deeply stained as to appear black.

Another method of detecting the presence of starch in vegetable structures is to boil for a few moments some fragments of the tissue to be tested in a few cc. of distilled water in a test-tube, and then, after the solution has cooled, drop in a little of the strong solution, when, if starch is present, the decoction will immediately acquire a blue color, the depth of which will depend on the quantity of starch present. On boiling the solution the blue color disappears, to reappear when cooling takes place.

Potassium Hydrate.—To prepare this reagent make a 10 per cent. solution of the pure fused potassium hydrate in distilled water, and keep it in well-stopped bottles. If corks are used, they should be paraffined, and if glass-stoppered bottles are employed, the stoppers should first be smeared with vaseline to prevent their sticking. This solution is useful as a clearing agent, since it rapidly dissolves the proteids and starch and saponifies and dissolves fats. It also stains corky tissues yellow or yellowish-brown, especially when warmed in contact with them, and tannin cells are also colored yellow or brown by it, though a better

test for tannin is a solution of some ferric salt. For clearing, the chloral-hydrate solution recommended in the Introduction to Part II. may be used instead, and in many cases is superior.

Ferric Chloride.—This solution is prepared by dissolving about 5 grammes of ferric chloride in 50 cc. of distilled water and adding a drop of nitric acid. The solution should be renewed from time to time. A drop of this solution applied to a section containing tannic matters will produce a bluish-black or a greenish-black precipitate, according to the variety of tannin that is present. Rarely, however, other substances present may produce similar precipitates with this reagent. Instead of this, there may be employed, with equal advantage, the ferric-alum solution described in the Introduction to Part II.

Phloroglucin Reagent.—This reagent consists of two liquids, which are to be kept in separate bottles: (1) a 5 per cent. solution of phloroglucin in 95 per cent. alcohol, and (2) strong hydrochloric acid. This is one of the most useful reagents, and is employed for distinguishing between lignified and unlignified tissues. The test is applied as follows: To a section of the tissue to be studied apply first a drop or two of the phloroglucin solution, and then, after a few moments, a similar quantity of the hydrochloric acid. If any lignified tissues are present, they will be stained red, while unlignified ones remain unstained. The arrangement of the bundles and that of bast-fibres and stone-cells may thus be traced with little difficulty.

Alcannin Solution.—This reagent is prepared by adding to a solution of alcannin in absolute alcohol an equal bulk of distilled water and then filtering it. It colors fats, volatile oils, and resins a deep red, and hence is a most convenient test for the presence of these bodies. The best results are obtained by letting sections soak in the solution for two hours or more. (See also Introduction to Part II.)

Preparation of Dried Material for Study.—Many dried materials, such as some medicinal roots, rhizomes, etc., may be studied quite satisfactorily in the dried form by making longitudinal and transverse sections and applying the appropriate tests. But more frequently the dried material is too hard, too friable, or too brittle to be satisfactorily studied in this way, and some preliminary treatment is necessary.

Except in the case of very hard tissues the following treatment is usually satisfactory: First soak the specimen in alcohol to expel the air; then (2) in water for a few hours until thoroughly permeated by the liquid; and then (3), if the tissues are too soft for satisfactory sectioning, as is frequently the case, particularly with herbaceous or succulent specimens, they should be hardened by immersion for at least twenty-four hours in strong alcohol. If now too hard or too brittle for cutting, they should be immersed in a mixture of equal parts of alcohol and glycerin for twenty-four hours.

According to the author's experience, the great majority of specimens of roots, rhizomes, tubers, corms, fruits, and seeds yield the best results when carried through all the stages of the process above described.

In the case of structures which, like gentian root, for example, have shrunken much in the process of drying, it is necessary, in order to restore them to their natural dimensions, to modify the second stage in the above process by using alkaline instead of pure water. A 1 per cent. solution of potassium hydrate in distilled water is suitable for most cases. Before hardening in alcohol it is advisable to wash out the alkali by means of pure water.

In the case of very hard tissues, such as shells of nuts, etc., softening is also effected by the use of the alkaline solution. The strength of the solution employed will depend somewhat on the nature of the tissues, but, as a usual thing, weak solutions, 1 or 2 per cent., are preferable to strong solutions. In some instances an immersion for several days will be required to effect the proper degree of softening. After this has been effected the tissues should be washed to get rid of the alkali, and then be transferred to glycerin, or to a mixture of equal parts of glycerin and alcohol, preparatory to sectioning.

In the case of dried leaves, flowers, or herbarium specimens, which it is desired to restore as nearly as possible to the condition of fresh specimens, it is usually sufficient to immerse them for a few hours either in 1 per cent. potassium-hydrate solution or in a weak solution of ammonium hydrate.

Examining Sections.—Explicit directions for sectioning are given in the Introduction to Part II., to which the student is referred. For the purposes of study by means of the simple

microscope it is not usually necessary to make sections so thin that they will freely transmit light; but it is necessary that they be made of nearly even thickness, and made with a very sharp knife, so that the tissues are not torn nor displaced.

For the purposes of this course two different kinds of sections are usually necessary—one transverse, and the other longitudinal—and great care should be taken that the former are strictly transverse or directly across the grain, and that the latter are strictly longitudinal. Oblique sections are worthless.

Immediately after cutting a section it should be transferred to water or to other liquid to prevent the entrance of air-bubbles, which obstruct the view of the structure, and which, having once entered, are very difficult to get rid of.

When sections are tested they should be transferred to a glass slide, and for study they should always be mounted in water, glycerin, or some other transparent liquid on a glass slide, and be covered with a cover-glass; otherwise the object will appear more or less distorted.

Care of Reagents and Apparatus.—The reagents are best kept in glass-capped bottles, such as those illustrated in the Introduction to Part II. Each bottle should contain a small glass tube to be used for transferring a few drops of the solution to the object to be tested, and great care should be exercised not to mix and spoil the reagents by putting the tubes into the wrong bottles. The student should bear in mind that some of the reagents employed are corrosive, and therefore should be on his guard against using them in a way that will injure his apparatus.

Whenever it is necessary to clean the lenses of the microscope, this should be done by means of a clean linen or a cotton cloth, or, better, by means of Japanese filter-paper, otherwise the lenses will be liable to be scratched or their polish impaired, to the detriment of their optical efficiency.

To reduce the labor of description to a minimum, and at the same time to ensure method and thoroughness, forms for the description of roots, stems, leaves, flowers, fruits, and seeds have been inserted at the close of these subjects respectively. These forms are also printed in separate record-books for the use of students.

EXERCISE I.

STUDY OF ROOTS.

SOME or all of the roots of the following plants may be studied: Dandelion (Taraxacum officinale, *Weber*), Yellow Dock (Rumex crispus, *L.*), Burdock (Arctium Lappa, *L.*), Carrot (Daucus Carota, *L.*), Radish (Raphanus Rhaphanistrum, *L.*), Salsify (Tragopogon porrifolius, *L.*), Maize (Zea Mays, *L.*), Smilax (Smilax rotundifolia, *L.*), Duckweed (Lemna polyrrhiza, *L.*), and English Ivy (Hedera helix, *L.*).

There is selected for the first study the root first mentioned, that of Dandelion. In removing it from the soil care should be taken that the root system be obtained as nearly uninjured and complete as possible. The plant should be taken up with an abundance of earth, and the latter washed away by holding it in a gentle stream of water, so that the finer branches may not be broken. Having obtained a satisfactory specimen, observe—

I. THE EXTERNAL CHARACTERISTICS.—(1) *Parts.*—The upper or ringed portion, from which the leaves spring or which shows the scars of leaves that have withered and disappeared, differs not only in appearance, but, as will presently be shown, also in internal structure, from the rest. It is, in fact, a stem, and not a part of the root. One of the characteristic differences between a root and a stem is that the latter bears leaves in some form, while the former does not. This stem, of which the root proper is the downward continuation, is technically called the *crown*. In the present instance, and in the roots of many other biennial or perennial herbs, the crown is liable to separate into several branches, each bearing a tuft of leaves. These branches are often called *heads*, and the root is then said to be many-headed. The junction of the crown with the root proper is termed the *neck*. In the Dandelion, and in very many other plants, but by no means in all, the root appears to be a downward prolongation of the stem. Such a root is called a *primary* root,

in distinction from one that springs out laterally from a stem, and which is called *secondary* or *adventitious*. Of the latter sort are the climbing rootlets of Poison Rhus, the air-roots of the Banyan, etc. Also, if, as in the Dandelion, the main root does not almost immediately break up into smaller ones, but maintains its ascendency over its branches until it reaches a considerable depth in the ground, it is called a *tap-root*.

On Plate I. (Fig. 1), *a* is one of the heads, *b* and *c* annular markings on the crown, and just below *c* is the neck.

(2) *Shape.*—The shapes of Dandelion roots vary considerably among themselves, but that of the one in the figure may be described as conical, since it tapers gradually from the crown downward.

(3) *Kind.*—As above stated, the root is primary and a tap-root.

(4) *Branches and Other Appendages.*—The main root frequently gives off one or more large branches, and always a multitude of smaller ones, and all these branches occur without definite order, as is frequently, though not always, the case with roots. In the Radish, for example, the branches occur mostly in two vertical rows on opposite sides of the main root.

It will be observed that the rootlets break up into finer and finer divisions, until the ultimate ones are quite minute, thus exposing a very considerable absorbing surface to the soil. This surface is still further greatly increased by the presence of vast numbers of root-hairs, which thickly clothe all the finer divisions of the root. In fact, these hairs, rather than the roots themselves, are the chief agents for absorbing nutriment from the soil. Some of them may readily be seen with a hand-magnifier or even with the naked eye, but unless the roots have been separated from the soil with extreme care they are mostly destroyed. They may be made to form again in great numbers, however, if, after removing the plant from the ground and washing it, the roots are kept for two or three days in a warm, moist, and dark chamber.

Exceptionally, roots bear buds, which may give rise to new stems, but adventitious buds of this kind seldom if ever occur on Dandelion roots.

(5) *Markings.*—Tuberculose or papillose markings may often be observed on the main root or on its larger branches, from which rootlets formerly issued, but have since disappeared. Frequently

also rough corky patches, caused by wounds that have healed or are in the process of healing, may be seen.

(6) *Color.*—The color of the uninjured root is usually light-brown or yellowish-brown in the younger, becoming darker in the older, portions. This color resides in the corky outside layer.

(7) *Measurements* should also be made of the roots studied, recording the length and greatest thickness. The one figured above, for example, has a length of about 18 cm. and a maximum thickness of about 1 cm., while that of the crown is about 1½ cm.

(8) The student should now make a drawing of the root which he is studying, indicating by aid of letters and lines the important structural points, as suggested in the model drawing (Pl. I. Fig. 1).

II. THE INTERNAL STRUCTURE.—The internal structure should be studied by making transverse and longitudinal sections, and applying to them such reagents as are necessary to reveal their structure more distinctly, and by examining them with a magnifying-glass.

(1) *Transverse Section of Root.*—Make two or three transverse sections, one just below the crown, the others lower down. They will differ in size, but it will be observed that they have substantially the same structure, except that possibly a small pith may be found in or near the centre of the upper one, but not in the others. The central yellowish portion, not more than about one-fourth the diameter of the entire section, is called the woody cylinder or *meditullium.* Surrounding this cylinder is the thick white bark, composed of softer tissues, from which, when fresh, there oozes a copious white milk-juice. This fluid, it will be observed, does not issue from the meditullium. The zone of junction between the meditullium and the bark constitutes the *cambium* zone, in which, in the roots and stems of gymnosperms and dicotyls during the growing season, increase in thickness takes place by the formation of new cells. To the naked eye or under an ordinary magnifier the cambium looks like a mere line, but it really consists of several layers of small very thin-walled cells.

The bark really consists of three layers. The outer, called the *epiphlœum,* is the thin, brownish, corky covering of the root;

the middle and inner layers are called respectively the *mesophlœum* and the *endophlœum*. In many roots these two layers appear quite distinct to the eye, but in the Dandelion their similarity in appearance is too close for this, and they can only be delimited clearly by aid of the compound microscope. With a magnifying power of about fifty diameters the inner bark shows a radial structure which the middle bark does not possess.

The milk-vessels are confined to these two layers, and their distribution in this root is quite peculiar. Observation shows that they are grouped in interrupted concentric circles (Pl. I. Fig. 3). The ringed appearance of the cross-section, observable even in the dried root, is due to this.

In the roots of most biennial and perennial dicotyls, and in those of gymnosperms, the meditullium shows a distinct radial structure consisting of medullary rays running from the centre across the cambium zone to the limits of the inner layer of the bark, and separating the wood into wedge-shaped bundles. This structure is present in the Dandelion root, though impossible to trace without the aid of a compound microscope. But no such structure exists in the roots of monocotyls.

(2) *Longitudinal Section.*—This section, if made through the centre of the root, shows that the meditullium is a ligneous cylinder extending from one end of the root to the other. Moreover, it sends branches not only into the larger, but also into all the finer, subdivisions of the root.

(3) *Tests.*—Certain reagents applied to the sections will enable one to learn some additional facts about the structure.

(*a*) *The Iodine Test.*—The thick, fleshy root evidently has stored within it much nutritive matter, to which is due the rapid unfolding of the leaves and flowers in the spring. Is a part of this food-material in the form of starch or not? The iodine test will answer the question. Applying a drop of potassium-iodide iodine to a cross-section, only a yellowish-brown color is produced. Had starch been present the reagent would have produced immediately a deep-blue color, appearing almost black if the solution used were a strong one. Whatever food-materials may be present, then, starch is certainly not one of them, widely distributed as this substance is in the vegetable world. The fact is, that in this plant, and in most others of the natural order to which it belongs,

the Compositæ, a related substance, inulin, which does not react blue with iodine, replaces starch as a reserve food-material.

Observing more closely the color-changes produced in the specimen by the iodine, it is found that the white tissues of the middle and inner bark have acquired a light yellowish-brown color, while the tissues of the meditullium have been stained a deep yellowish-brown. The color of the former is chiefly due to the presence of albuminous matters in the bark-cells, while that of the latter is caused by the presence of lignin or woody matter in the cell-walls of the meditullium. It is thus learned that the iodine stains albuminous substances light yellowish-brown, lignified cell-walls deep yellowish-brown, and the walls of ordinary thin-walled cells scarcely at all.

(*b*) *The Phloroglucin Test.*—To a fresh cross-section apply first two or three drops of a 5 per cent. alcoholic solution of phloroglucin, and, after a few moments, two or three drops of strong hydrochloric acid. Presently a deep-red color will be developed in the meditullium, while the rest of the section will remain wholly unstained. Since this reagent stains no tissues red excepting lignified ones, it confirms one of the results obtained by the iodine test. This test is of great value in the investigation of roots and stems, for it often beautifully differentiates structures which without its aid might not easily be distinguished.

(*c*) *The Ferric-chloride Test.*—If tannic matters occur in tissues, the fact is revealed by applying a little of this reagent to a section, when a greenish-black or bluish-black precipitate will be produced. Other than tannic matters, however, capable of similar reactions with ferric chloride, sometimes occur in plants, so one should be cautious about drawing conclusions based on this test alone. But the test is of value in another way. If tannic or other matters producing a precipitate be present, their greater abundance in some tissues than in others, or their total absence in some and abundance in others, are often a means of revealing structure more clearly; for example, by bringing the medullary rays into greater prominence, rendering the bark more distinct from the wood, or the cambium zone more conspicuous.

In the present case, however, a drop of the reagent applied to the surface of a fresh section produces scarcely any change of

color. Dandelion root, therefore, ordinarily at least, contains little if any tannin.

(4) *Drawing.*—On a scale large enough clearly to indicate the important points in the structure make a drawing of the transverse section, indicating the different parts by aid of letters and lines as suggested on Plate I. (Fig. 3).

(5) *Transverse Section of the Crown.*—Make two or three transverse sections at different levels, and compare them carefully with the ones already studied of the root. It will be observed that the woody cylinder is relatively thicker than in the latter; that it has a distinct pith; that the radial structure of the meditullium is much more distinct than in the root; and that these differences are more conspicuous a few millimetres above and below the neck than they are near it, where there is a gradual transition of one organ into the other. Draw a diagram of one of the cross-sections and indicate the parts, as in Figure 2 (Pl. I.).

If the tips of any one of the hundreds of small root-branches of the Dandelion were examined under a compound microscope, each would be found to possess a cap of older and thicker-walled cells, whose function it is to protect the growing point, which lies a little way back of the apex, during the movements of the rootlets through the soil. The structure is shown in Figure 4 (Pl. I). This protective covering is called the *root-cap.* In some plants, as the Duckweeds (Lemna minor and L. polyrrhiza), it is large enough to be seen easily with the naked eye.

Now, in a similar manner, study, describe, and figure one of the five following roots: Yellow Dock, Burdock, Carrot, Radish, or Salsify, all dicotyls, and afterward compare the selected root carefully with the roots of Maize or of Smilax, which are monocotyls. Note carefully all the important points of difference in structure and habit.

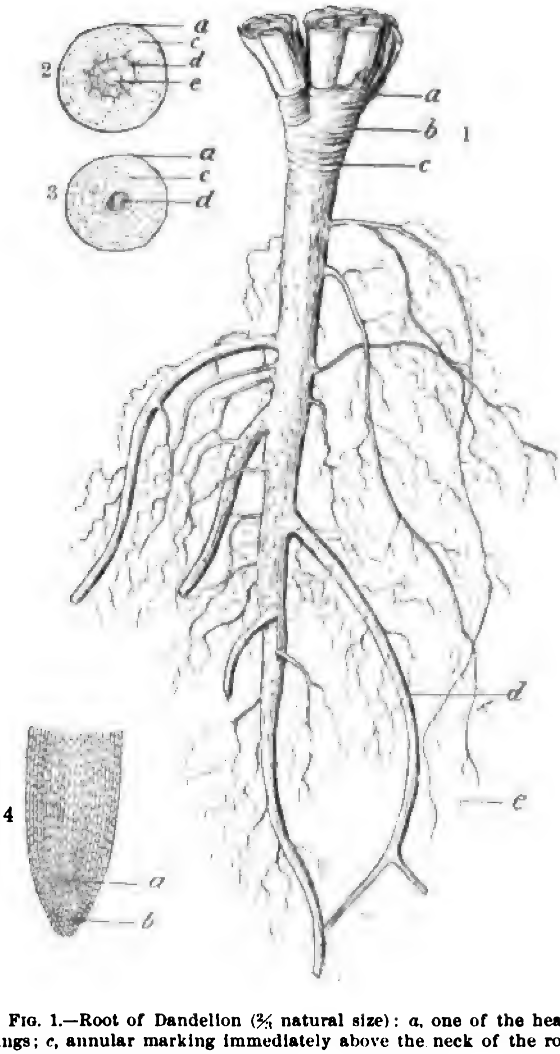


PLATE I., FIG. 1.—Root of Dandelion (⅔ natural size): *a*, one of the heads; *b*, annular markings; *c*, annular marking immediately above the neck of the root; *d*, one of the larger root-branches; *e*, one of the finer branches or fibrils.

FIG. 2.—Diagram of Cross-section of the Crown (magnified 1½ diameters): *a*, corky layer of the bark: *c*, circularly arranged milk-vessels; *d*, woody cylinder crossed by medullary rays and containing a pith, *e*, in the centre.

FIG. 3.—Diagram of the Cross-section of the Main Root a little below the neck (magnified 1¼ diameters): *a*, corky layer of bark; *c*, concentrically arranged milk-vessels; *d*, central cylinder.

FIG. 4.—Tip of Small Root (magnified about 50 diameters), showing growing-point (*a*) and root-cap (*b*).

FORM FOR STUDY OF ROOTS.

I. KIND.
  1. Primary.
  2. Adventitious.

II. FORM.
  1. Simple.
  2. Branching.
  3. Conical.
  4. Fusiform.
  5. Napiform.
  6. Fasciculate
  7. Fibrous.

III. SIZE.
  1. Length.
  2. Greatest thickness.

IV. COMPOSITION.
  1. Many-headed.
  2. Few-headed.
  3. Single-headed

V. MARKINGS.
  1. Annulate.
  2. Warty.
  3. Wrinkled.
  4. Keeled.
  5. Fissured.
    Transversely.
    Longitudinally.

VI. FRACTURE.
  1. Short.
  2. Brittle.
  3. Splintery.
  4. Fibrous.
  5. Horny.
  6. Corky.
  7. Mealy.
  8. Friable.

VII. COLOR.
  1. Exterior.
  2. Interior.

VIII. TASTE.
  1. Insipid.
  2. Bland.
  3. Sweet.
  4. Bitter.
  5. Mucilaginous.
  6. Pungent.
  7. Acrid.
  8. Warm.
  9. Cooling.
  10. Astringent.
  11. Nauseous.
  12. Burning.
  13. Prickling.
  14. Saline.
  15. Alkaline.
  16. Acidulous.

IX. ODOR.
  1. Odorless.
  2. Faint.
  3. Agreeable.
  4. Aromatic.
  5. Mint-like.
  6. Balsamic.
  7. Camphoraceous.
  8. Terebinthinous.
  9. Pungent.
  10. Musky.
  11. Disagreeable.
  12. Irritating.
  13. Nauseous.
  14. Narcotic.
  15. Putrid.
  16. Fetid.

X. INTERNAL STRUCTURE.
  1. *Monocotyl type.*
    (1) Cylinder-sheath.
      a. Distinct.
      b. Indistinct.
      c. Lignified.
      d. Unlignified.
    (2) Cortex.
      a. Thickness compared with central cylinder.
      b. Bundles in:
        Numerous.
        Few or none.
        Lignified.
        Unlignified.
    (3) Central cylinder.
      a. Rays in:
        Numerous.
        Few.
        Lignified.
        Unlignified.
    (4) Starch.
      a. Most abundant in cortex.
      b. Most abundant in central cylinder.
    (5) Tannic matters.
      a. Most abundant in cortex.
      b. Most abundant in central cylinder.
  2. *Dicotyl type.*
    (1) Cambium zone.
      a. Distinct.
      b. Indistinct.
    (2) Bark.
      a. Thickness relative to wood.
      b. Layers.
        Indistinct.
        Distinct.
        Relative thickness of—
          Exophlœum.
          Mesophlœum.
          Endophlœum.
      c. Mesophlœum.
        Stone-cells.
          Numerous.
          Few.
      d. Endophlœum.
        Distinctly radiate.
        Indistinctly "
        Not radiate.
        Bast-masses.
          Stratified.
          Unstratified.
          Shape.
            Conical.
            Linear.
            Oblique.
            Curved.
          Bast-fibres.
            Numerous.
            Few.
            Strongly lignified.
            Slightly "
            Unlignified.
    (3) Woody cylinder.
      a. Distinctly radiate.
      b. Indistinctly radiate.
      c. Annulate.
      d. Medullary rays.
        Narrow.
        Medium.
        Broad.
        Lignified.
        Unlignified.
      e. Xylem wedges.
        Narrow.
        Medium.
        Broad.
        Lignified.
        Unlignified.
      f. Ducts.
        Conspicuous.
        Inconspicuous.
        Numerous.
        Few.
      g. Fissuring.
        Fissured.
        Entire.
    (4) Starch.
      a. Most abundant in—
        Mesophlœum.
        Endophlœum.
        Medullary rays.
        Xylem wedges.
      b. No starch.
    (5) Tannic matters.
      a. Most abundant in—
        Exophlœum.
        Mesophlœum.
        Endophlœum.
        Cambium zone.
        Medullary rays.
        Xylem wedges.
      b. No tannic matters.

EXERCISE II.

STUDY OF STEMS.

SOME or all of the following stems may be studied: Twigs of Hickory (Carya alba, *Nutt.*), Horse-chestnut (Æsculus Hippocastanum, *L.*), Balsam Poplar (Populus balsamifera, *L.*), Ash (Fraxinus Americana, *L.*), Lilac (Syringa vulgaris, *L.*), Maple (Acer dasycarpum, *Ehrh.*), Basswood (Tilia Americana, *L.*), the climbing stems of Green Briar (Smilax rotundifolia, *L.*), and the herbaceous stems of Sunflower (Helianthus annuus, *L.*), and Maize (Zea Mays, *L.*).

Let there first be examined carefully a twig of the common Shellbark Hickory, and the study of this will form a basis for the study of the rest. Any well-developed twig of the tree, representing a growth of at least two years and gathered late in autumn or in early spring before the leaves unfold, will serve the purpose.

I. THE EXTERNAL CHARACTERISTICS.—*Parts and Markings.*—(1) At the apex or upper end of the twig is observed a large scaly bud called the *terminal bud.* Below this, at intervals along the stem, are other buds, smaller in size, but otherwise similar. These buds, since they occur just above where the leaf of the previous season joined the stem, are called *axillary* buds. The heart-shaped scar caused by the fall of the leaf may be seen immediately below the bud in each case. These buds and leaf-scars, it should be observed, are not arranged without order, but in a regular spiral about the stem.

If the twig has had a rapid growth, we are liable to find more than one bud, sometimes as many as three, in or near the leaf-axil. In the Hickory these buds are arranged one above the other, the smallest nearest the leaf-scar, the next larger just above this, and the largest most remote from the scar. The real axillary bud is the first mentioned and smallest; the others are called *supernumerary* buds.

In some other members of the Walnut family, to which the Hickory belongs—as, for example, the Bitternut Hickory—these vertically arranged supernumerary buds are nearly always present. A more common arrangement of these buds is seen in the Red Maple, the Tartarian Honeysuckle, and the wild Black Currant, where the supernumeraries occur alongside of or on the same level with, and not above, the axillary bud.

(2) Some distance down the twig from the terminal bud will be seen a series of closely-arranged, ring-like scars. These mark the position of the terminal bud of the previous year; they are, in fact, the scars left by the falling off of its scales. They are indicated at *f* in Figure I (Pl. II.).

(3) Minute dots, slight elevations in its corky exterior layer, may also be seen freely sprinkled over the surface of the twig. These dots are called *lenticels*, and are probably serviceable in the respiration of the plant. Their structure cannot well be understood without the aid of a compound microscope.

(4) Enough of the twig which the student is studying should now be drawn to show a little more than the last year's growth, and the following parts should be pointed out: A terminal bud, an axillary bud, a supernumerary bud (if present), a leaf-scar, a lenticel, and one of the ring-like scale-scars at the base of the year's growth.

II. Structure of the Terminal Bud.—(1) Cut the twig in two, transversely, about ½ cm. below the terminal bud; split the part bearing the latter from below upward, letting the section pass as nearly as possible through the centre of the bud. If the section has been well made with a thoroughly sharpened knife, the structure may now be distinctly seen. It will be observed that the bud consists of a series of thin layers or scales, one within the other, and each inserted upon the short-conical prolongation of the axis or stem. The scales, in fact, represent leaves, and the leaves, as is always the case with these organs, are borne upon a stem. A bud, therefore, is a short stem with leaves very compactly arranged upon it.

(2) From one-half of the divided bud remove the scales one by one, beginning with the outer. It will be seen that they are not all alike. The outer ones are not so large as those next interior, and are thicker and more woody. They are, moreover,

smooth or nearly so, while the thin interior ones are densely clothed with appressed silky hairs. These two kinds of scales are leaves modified for the protection of the delicate true leaves which they enclose. When the bud unfolds in the spring, the outer scales fall away unchanged, but the inner ones, especially those next the true leaves, make a feeble effort to become foliage: they increase considerably in size and acquire some greenness of color, but soon fall away, yielding to the expanding foliage leaves. The more woody outer scales doubtless protect the true leaves from mechanical violence, such, for example, as that due to the lashing of the branches during a storm; while the plush-covered inner ones protect them from sudden changes of temperature and from the entrance of water. This latter is accomplished partly by the closeness with which the scales are applied to one another, and partly by their downy covering, which is somewhat oily and so repels the water. If water were permitted free access to the interior, its freezing and thawing in winter would, beyond question, harm or destroy the young and delicate foliage leaves within.

Examining now the true leaves, it will be found that there are several of these, small in size, but with their parts distinctly recognizable under the magnifying-glass. They occur very near to, but just back of, the stem-apex, the youngest and smallest nearest of all. The glass shows that these leaves are already compound, thus contrasting strongly with the scales, which are simple.

The leaflets are densely clothed with hairs, partly glandular and partly of the ordinary kind, both probably protective in their function, but the former, in particular, useful in defending the young and growing leaves from the attacks of injurious insects.

Packed away in small compass within the bud is the leafy branch of the coming year, awaiting only the genial warmth and moisture of spring to bring it to its full development.

(3) Make a drawing of one-half of the bud, enlarged about three diameters, as suggested on Plate II. (Fig. 2), and point out one of the outer bud-scales, one of the inner hairy scales, one of the true leaves, the stem-apex, the pith, the wood, and the bark.

III. Internal Structure of the Stem.—For this part of our study transverse and longitudinal sections must be made and suitable reagents must be applied to bring out the structure more

distinctly. Make several cross-sections, one through the younger portion of the stem, the growth of last year, one through a portion two years old, and a third through a part still older.

(1) Without staining them, examine these sections successively with a magnifying-glass. Each will be seen to possess in the centre an angular *pith* surrounded by a layer of white *wood*, which in the first section is rather thin, in the second thicker and made up of two rings called *rings of growth*, and in the third still thicker and made up of three or more rings, one ring being added, as a rule, for each year's growth. It will also be seen that the wood is crossed in a radial direction by very numerous delicate lines which have their origin in the pith and terminate in the bark. These are called *medullary rays.*

Outside the wood occurs the bark, which is also thinner in the younger part of the stem and thicker in the older portions, though this difference is less marked than in the case of the wood. With care the bark may, as in the root of Dandelion, be distinguished into three layers: an outer, the grayish or brownish corky layer, called the epiphlœum; next the latter a middle layer composed chiefly of green cells, and hence called the green layer, or, from its position, the mesophlœum; and an inner layer or zone called the endophlœum, or bast-layer, which may be observed to contain numerous masses of bast-fibres distributed through softer tissues. The former appear whitish under the magnifying-glass.

The delicate tissue constituting a thin boundary-zone between wood and bark is also called *cambium,* and here, as in the Dandelion root, throughout the season of growth new cells are formed which add to the thickness of the wood on the outside and to that of the bark on the inside.

(2) *Apply the phloroglucin test.* The purpose of this test is to differentiate the parts, so that the structure may be more easily understood. Apply to each of the three sections the test in the same manner as directed in Exercise I. The pith and wood in each case, it will be observed, are stained red, though of somewhat different shades, and in the older portions of the stem, at least, the bast-fibres in the inner layer of the bark also stain, so that they are now more distinctly recognizable. All the other tissues remain unstained. The bast-fibres form wedge-shaped masses, with the thinner end of the wedge outward and each mass crossed

both radially and tangentially by softer tissues. In the older stems these wedges are larger, particularly longer in a radial direction.

The staining of the fibres aids in tracing the limits of the inner bark, since the latter constitutes a zone bounded on the outside by a circular line joining the outer limits of the bast-wedges. Moreover, the ends of the medullary rays which penetrate the bark may now be traced more easily. The coarser rays are made up of the soft tissues which separate laterally the bast-wedges; and the finer, of those which traverse the wedges in a radial direction. The rays extend to, but do not penetrate, the middle bark. The inner bark may therefore usually be distinguished from the middle by its radial structure.

In many stems, though not in the Hickory, the phloroglucin test also enables one to see the medullary rays in the wood more distinctly.

(3) *Apply the iodine test.* This test is used as directed in Exercise I., and for the same purpose. It will be observed that starch occurs in the bark (particularly in the middle layer), in the pith (especially in its outer portion), and in the medullary rays. The latter are therefore rendered very distinct by this test.

(4) *Apply the ferric-chloride test.* Using this test as directed in Exercise I., it will be found that tannic matters occur more abundantly in the medullary rays than in the wood, that the pith contains but little tannin, and that the bark contains it in abundance.

(5) *Draw a diagram of the cross-section of the stem,* selecting for the purpose a part which is at least two years old. Let the structure be represented as magnified about five diameters, as in Pl. II. Fig. 3. Point out the epiphlœum, the mesophlœum, the endophlœum, the cambium zone, a wood wedge, a medullary ray, a ring of growth, and the pith.

(6) *Study the longitudinal section.* Take a fresh twig, and with a sharp knife make a section lengthwise through the middle, preferably from the base upward, so guiding the knife that one of the axillary buds will be bisected. Apply to the cut surfaces such tests as are necessary to render the structure distinct. Observe that the pith traverses the stem lengthwise from end to end, penetrating even the axis of the terminal bud and sending off branches

to the axillary ones. On either side of the pith will be seen a white band of wood; adjacent to each of these bands, on the outside, a thin cambium line; and next, a broader band of bast, the long fibres of which make this layer of the bark appear quite different from the other two layers, which may also be traced as thin longitudinal bands. We can easily see, from a comparison of the transverse and longitudinal sections, that the stem is made up of a series of cylinders: first, the solid pith; then a hollow cylinder of wood enclosing it; this in turn is enclosed by a thin cylinder of cambium, this by a cylinder of bast, this by one of mesophlœum, and the whole enveloped by a cylinder of epiphlœum; the tissues of these cylinders, however, not being distinct, but continuous from one to the other, forming a solid whole.

Such is the structure of the Hickory twig; and its study has given not only a good idea of Hickory stems in general—for they differ mainly in size and in the relative thickness of certain layers—but has afforded a very good general knowledge of the structure of the stems of nearly all dicotyls and gymnosperms.

While the stems of these plants differ in numerous structural details, the general arrangement of tissues is the same in all. There is a central pith surrounded by a cylinder of wood which is crossed by medullary rays; this is enclosed by a cylinder of cambium, and this by a three-layered cylinder of bark. As will be seen hereafter, this arrangement is widely different from that found in the stems of ferns and monocotyls.

Now let the student, pursuing the same method, study, describe, and figure twigs of one or more of the following plants: Horse-chestnut, Balsam Poplar, White Ash, Lilac, or any one of the other plants mentioned at the beginning of this exercise.

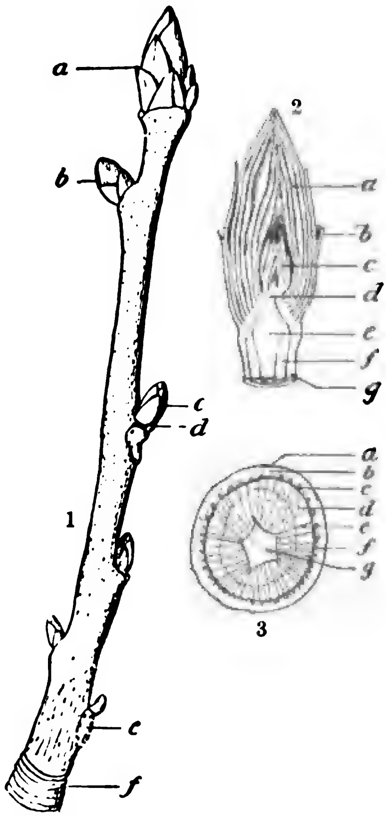


PLATE II., FIG. 1.—Drawing of a Hickory Twig, including about one year's growth ($\frac{3}{4}$ natural size): *a*, terminal bud; *b*, *d*, axillary buds; *c*, supernumerary bud; *e*, leaf-scar; *f*, scars of scales of last year's terminal bud.

FIG. 2.—Drawing of Vertical Section of Terminal Bud of Hickory (magnified about 2 diameters): *a*, one of the inner, hairy scales; *b*, one of the outer, woody scales; *c*, one of the true leaves; *d*, the stem-apex; *e*, the pith; *f*, the wood; *g*, the bark.

FIG. 3.—Diagram of Cross-section of Hickory Twig, representing two years' growth (magnified about 3 diameters): *a*, outer bark or epiphlœum; *b*, middle bark or mesophlœum; *c*, inner bark or endophlœum; *d*, wood; *e*, medullary ray; *f*, ring of growth; *g*, pith.

EXERCISE III.

STUDY OF STEMS: COMPARISON OF TWIGS.

TWIGS from any of our common trees or shrubs, collected in late autumn or in early spring, will afford very instructive studies. For the purposes of this exercise the four following are selected: those of the American Beech (Fagus ferruginea, *Ait.*), those of the White Ash (Fraxinus Americana, *L.*), those of the Basswood (Tilia Americana, *L.*), and those of the Balsam Poplar (Populus balsamifera, *L.*).

Directing attention first to the Beech twig, let its peculiarities be noted and its structure be compared with that of the others.

I. EXTERNAL CHARACTERISTICS.—Note, first, that the Beech twig is thin, cylindrical, its grayish exterior or corky layer freely punctate with lenticels which are smaller than those already observed in the Hickory. It is also somewhat zigzag, being bent at the points where the axillary buds occur. At the ends of branches and in the axils of leaf-scars are observed also prominent scaly buds, and at intervals along the twigs or at the bases of the shorter branches compact clusters of ring-like scale-scars marking the position of the buds of previous years; but rarely if ever are any adventitious buds or supernumerary ones to be found.

(1) *Phyllotaxy.*—But the most conspicuous differences between the Beech twig and the Hickory twig are to be found in the form and arrangement of the leaf-scars and that of the scales of the scaly buds. Especial attention, therefore, should be given to these points.

Observe, first, that there is only one leaf-scar at a node; and, second, that the next one higher up on the stem is halfway around from the first, or on the opposite side, so that there are on the stem two vertical rows of scars and axillary buds. Now, nearly all stems show a great regularity in the arrangement of the leaves, but this arrangement is by no means the same in different

plants. In the Hickory the arrangement is different from that in the Beech, and different still from both in the Ash. In fact, two different types of arrangement may be distinguished—the *alternate* and the *whorled*. In the former only one leaf occurs at a node; in the latter two or more; but there are many varieties of each of these. The Beech presents a very simple variety of the former, and the leaf-arrangement—or *phyllotaxy*, as it is technically called—is expressed by the fraction one-half. In this fraction the numerator expresses the number of turns about the stem to complete a cycle, and the denominator the number of leaves included in the cycle. The fraction also expresses the angular distance between successive leaves, one-half the circumference of the stem, or 180°, intervening between one leaf and the next in the cycle. The denominator of the fraction, moreover, expresses the number of vertical rows of leaves, or *orthostachies*, on the stem.

If the phyllotaxy of the Beech be compared with that of the Hickory twig, it will be found that the latter also is alternate; but the fraction which expresses it is different. If, as in studying the Beech twig, the start be made with a leaf-scar low down on the stem, and a line be traced around it to the next scar, and so on until the scar is reached directly over the one from which the start was made, it will be found that it is the sixth leaf instead of the third that is directly over the first; that five scars have been passed in going from one to the other, not counting the last; and that two circuits of the stem have been made. The fraction which expresses the phyllotaxy is therefore two-fifths.

Similarly examining other alternate-leaved twigs, it will be found that the phyllotaxies $\frac{1}{3}$, $\frac{3}{8}$, or $\frac{5}{13}$ also exist. Putting these fractions together in order, it will be found that they form a series, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, etc., which includes by far the larger proportion of all alternate forms of phyllotaxy. The members of this series bear a very curious relation to each other. If the numerators of the first two be added together for a new numerator, and their denominators for a new denominator, the third fraction in the series is obtained; if the second and third be similarly treated, the fourth term is obtained; and so on.

The Basswood twig agrees with the Beech in its phyllotaxy, and that of the Balsam Poplar with the Hickory; but in the twig of the Ash there are two leaf-scars and two buds at a node;

this affords an illustration of the other type of phyllotaxy—namely, the *whorled*. It is also the simplest form of this arrangement. It will be observed that the leaves composing the whorl are as far apart as possible—namely, opposite each other on the stem, and this variety of the whorled node has hence been called the opposite. It is almost universally the case, whether the leaves in the whorl be few or many, that they are placed at equal distances apart; if two, 180° apart; if three, 120°; and so on.

It will furthermore be seen that the successive whorls alternate; that is, if a line were drawn through the centre of a pair of leaf-scars, this line would cross at right angles one drawn through the centre of the pair of scars next below or of the ones next above. The whorls, in other words, are *decussate*, and this, too, is nearly always true of whorled leaves. Thus, in the phyllotaxy where the leaves are opposite or in whorls of two there will be four vertical rows of leaves on the stem; where they are in whorls of three, six rows; and, in general, there are twice as many vertical rows as there are leaves in the whorl.

All this doubtless has reference to securing for the leaves their due proportion of light—a thing necessary to the proper performance of their functions and to the prevention of interference between the nutritive currents that flow between the leaves and the stem.

(2) *Leaf-scars.*—Comparing the scars on the different twigs studied, very considerable differences will be found between them, not only in size, number, and arrangement, but in their shape, in their markings, and in their position as respects the axillary bud. In the Beech they are small, nearly semicircular in outline, dotted with the scars of several (about seven) leaf-bundles arranged in a semicircle, and bordered on either side by line-like stipule scars. The bud is not located directly in the axil of the leaf-scar, but above and somewhat to one side. Those of the Basswood are similar in shape, but larger, the buds are strictly axillary, and the bundle-dots in the leaf-scars are unequal in size and usually about six in number.

In the Balsam Poplar the scar is conspicuous, few-dotted, usually with a broadly rounded sinus above, into which the bud fits, and the lower end is pointed.

The leaf-scars of the Ash are still more prominent, many-dotted,

rounded on the sides and lower edge, and either straight on the upper margin or with a shallow sinus into which the bud fits.

Many other interesting variations in the scars would be found if other twigs were studied; for example, those of the Ailanthus, the Sumach, and the Aralia spinosa are enormously large, and those of the Sycamore completely encircle the bud, the leaf-base fitting over it in the growing season like a candle-extinguisher.

(3) *Bud-scales.*—Since these are modified leaves or portions of leaves, one would naturally expect to find their phyllotaxy in agreement with that of the foliage leaves of the same plant. This is, in fact, the case in most instances, but there are some exceptions, apparent or real. In the Beech, for example, there are four vertical rows of scales in the bud, and but two of ordinary leaves. This deviation can be accounted for readily by supposing that the scales represent the pairs of stipules at the bases of leaves rather than the leaf-blade; and this is probably the fact.

In the Ash, the Basswood, and the Balsam Poplar, however, the arrangement of the scales is precisely that of the true leaves.

So many interesting peculiarities do the buds and leaf-scars of the branches of different trees and shrubs present that it would probably be possible, by aid of them, to construct a key for identification of our native species.

The student should now make drawings and descriptions of an equal number of twigs taken from other trees or shrubs.

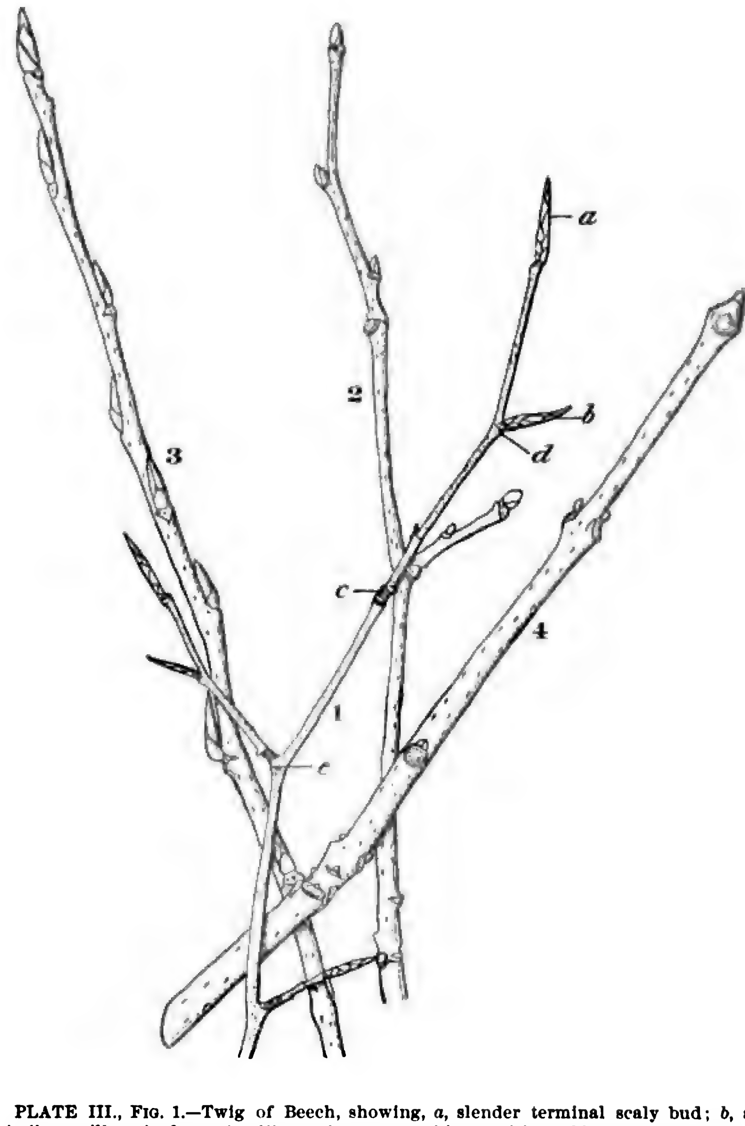


PLATE III., Fig. 1.—Twig of Beech, showing, *a*, slender terminal scaly bud; *b*, a similar axillary bud; *c*, ring-like scale-scars marking position of last year's terminal bud; *d*, leaf-scar; *e*, stipule-scar. The small dots sprinkled over the stem represent the lenticels.

Fig. 2.—Twig of Basswood, showing one-half phyllotaxy, like that of Beech.

Fig. 3.—Twig of Balsam Poplar, showing two-fifths phyllotaxy.

Fig. 4.—Twig of Ash, showing opposite phyllotaxy. (Each about ⅔ natural size.)

EXERCISE IV.

STUDY OF STEMS: THE RHIZOME.

Among dicotyls any of the following plants will afford good material for study: The Mayapple (Podophyllum peltatum, *L.*), Culver's-root (Veronica Virginica, *L.*), Cranesbill (Geranium maculatum, *L.*), Blue Cohosh (Caulophyllum thalictroides, *Michx.*), Peppermint (Mentha piperita, *L.*), and Yellow Parilla (Menispermum Canadense, *L.*).

Among monocotyls the following will afford instructive studies: Solomon's Seal (Polygonatum biflorum, *Ell.*, or P. giganteum, *Dietrich*), Sweet Flag (Acorus Calamus, *L.*), Blue Flag (Iris versicolor, *L.*), False Solomon's Seal (Smilacina racemosa, *Desf.*), and Lily-of-the-Valley (Convallaria majalis, *L.*). One rhizome from each group will be studied in this exercise.

A.—For our first study the rhizome of Mayapple will be selected. Rhizomes gathered in late autumn or in early spring are the most suitable for the purpose, and the description which follows applies to such:

I. External Characteristics.—(1) Removing the rhizome carefully from the soil, it will be found that its length varies from two to four feet; that it grows horizontally two or three inches beneath the surface of the ground; that, except for the swollen nodes that occur along it at intervals of from two to four or five inches, it is nearly cylindrical; that from these nodes it sends out occasional lateral branches similar to the parent rhizome; and that the posterior or older end of the rhizome is in process of decay, showing that increase in length is limited, and that as it grows at the apex it becomes exhausted and dies away at the base. Each plant is thus year by year slowly travelling through the soil; moreover, by reason of the lateral branches which, by this process, must sooner or later be-

come detached from the parent rhizome, a large number of new plants must ultimately originate.

It will be observed further that the rhizome is thick and fleshy, containing large stores of food-material to supply the growth of above-ground parts when the warm spring sunshine stimulates the vital processes of the plant to renewed activity.

Examining carefully the brownish surface, there will be found between the more conspicuous nodes angular scars, the scars of scales that have decayed. These, since they represent leaves, prove the rhizome to be a stem rather than a root, because roots never bear leaves.

On the upper sides of the enlarged nodes will be observed conspicuous circular scars, shown at *d* on Plate IV. (Fig. 1). These are either cup-shaped or there is a central conical elevation, in reality a small bud. The former are scars of the above-ground stems; the latter, scars of the large radical leaves of previous seasons.

From the sides and lower surfaces of the rhizome, at or near the enlarged nodes, arise numerous small roots. These differ in origin from the Dandelion root, being outgrowths from the side of the stem, and not from its end. They are therefore adventitious, and not primary roots. The lateral roots borne by rhizomes must, of course, always be adventitious.

Ascending, or sometimes arising nearly at right angles, from the end of the rhizome and from the ends of each of the main branches will be observed conspicuous buds, which remind one, except from the texture of the scales, of the terminal bud of the Hickory. These buds give origin to an above-ground stem or leaf, which, when it decays in autumn, leaves a large circular scar, such as has already been observed at the swollen nodes. In the mean time, through the summer, the rhizome is pushing onward through the soil, and at the close of summer has formed a new bud at its apex. The number of circular scars, therefore, may indicate the age of the rhizome.

(2) Now make a drawing of the rhizome, pointing out the following parts: one of the angular scale-scars; the terminal bud; a branch; one of the large circular scars; and one of the secondary roots.

II. STRUCTURE OF THE TERMINAL BUD.—(1) Cut the rhizome in two a little way back from the terminal bud, and then split it

from below upward through the middle. Some specimens will show the structure illustrated on Plate IV. (Fig. 2). The scales are much alike except for size, and they are not dry, like those of the Hickory, nor are any of them clothed with hairs or otherwise constructed with reference to the exclusion of water or the prevention of sudden changes of temperature. Being under ground, they do not need to be thus protected, the soil itself serving the purpose perfectly. Their main use seems to be to protect the true leaves and stem-apex from mechanical injury as it grows onward through the soil.

Some of the inner scales, like the corresponding ones of the Hickory, develop considerably in the spring, and often even rise a little above the soil; but they soon wither away, leaving ring-like scars on the part of the rhizome which bore them. These are shown at *e* on Plate IV. (Fig. 1).

Interior to the scales, and enclosed by them, will be found a single well-developed peltate leaf having its lobed blade plicately folded down over the cylindrical petiole, as shown in the figure. These leaves, when mature, may reach to the height of a foot, or even two feet, above the soil, and the blades may attain the diameter of a foot.

The section of the bud shows at the base of the petiole a very minute bud; in fact, the petiole fits over the latter like a candle-extinguisher. When, in the autumn, the leaf falls away, this bud appears as the conical point, already alluded to, in the centre of the large circular scar that marks the insertion of the petiole.

Besides this bud, the section shows still another, indicated at *c* in the figure. It usually occurs, as in the case illustrated, on the under side of the rhizome in the axil of one of the outer scales of the terminal bud. This axillary bud serves to continue the growth of the rhizome under ground, and the angular scars already referred to are the scars of its scales, the latter being carried apart by the lengthening of the bud-axis, and then withering away.

There may also be other buds situated just back of the apical ones, giving rise to lateral offshoots from the rhizome.

(2) Make a drawing of such a bud, magnified about two diameters, and point out a bud-scale, the petiole of the true leaf, the

bud that occurs at its base, and the bud that serves to continue the growth of the rhizome.

(3) Other terminal buds show a structure different from that described above. Instead of a single large leaf in the interior, will be found a stem with two opposite leaves upon it and terminated by a well-developed flower-bud, as shown on Plate IV. (Fig. 3). This stem when fully grown attains about the same diameter and height as the petiole of the leaf in the former case, and it has much the same appearance, but that it is really a stem is shown by the fact that it produces a flower and fruit. Moreover, no bud forms underneath it, and when it disappears in autumn it leaves a cup-shaped scar, and not one with a conical elevation in its centre.

(4) Make a drawing of a vertical section of one of these buds also, magnified about two diameters, and point out a bud-scale, the enclosed stem, the bud that serves to continue the growth of the rhizome, a true leaf, and the flower-bud.

III. THE INTERNAL STRUCTURE OF THE RHIZOME.—Podophyllum is a dicotyl, though one of altogether different habit from that of the Hickory. Moreover, the stem of the Hickory which has been studied was an above-ground one, while this is an underground one. Great differences of structure are therefore to be expected; but can the same general plan or type of structure be traced in both? Let us see.

(1) Making a cross-section and treating it with the phloroglucin reagent, about midway between the circumference and the centre of the section will be found a circle of red dots from twelve to twenty in number. These circles, though few and small compared with those of the Hickory, are the wood or vasal bundles; the soft area enclosed within the circle constitutes the pith; and the bands of soft tissue which separate the bundles laterally from each other are the medullary rays.

If with the glass the bundles be carefully examined, each will be found to have an inner part which is stained, or partly so, by the phloroglucin, and an outer part which is wholly unstained, yet distinct enough from the adjacent soft tissues. The former is the wood or the xylem; the latter, the bast or phloem of the bundle. Extending in a circle about the stem, between the wood and bast, is the cambium; the bast portions of the bundles, to-

gether with those portions of the medullary rays exterior to the cambium zone, constitute the inner bark; the soft white tissues still farther exterior make up the middle bark; and the exterior brownish, corky layer is the outer bark.

It is thus seen that in all the essential features of its structure this stem agrees with that of the Hickory. It clearly belongs to the same type. In many details, however, it differs from the latter. For example, it has but little lignified tissue; its vasal bundles are shorter, broader, and fewer; there are either no bast-fibres or rarely very imperfectly developed ones; the pith is relatively larger, is cylindrical, and is not composed of dead cells; and its soft tissues contain a much greater abundance of starch, as revealed by the iodine test.

(2) Make a drawing of the cross-section, magnified three or four diameters, and point out the following parts: the outer bark; the middle bark; a bast-bundle in the inner bark; the cambium zone; the wood of a bundle; and the pith.

B.—The rhizome of a monocotyl will now be studied, that of Solomon's Seal (Polygonatum biflorum) being selected for the purpose.

I. EXTERNAL APPEARANCE AND CHARACTERISTICS.—(1) Note first the more obvious resemblances and differences between this rhizome and that of the Mayapple, just studied. The former resembles the latter in the following particulars: it creeps horizontally; it has numerous scale-scars along its sides; it has circular depressed scars on its upper surface; it has prominent nodes at the points where these scars occur; it has a conspicuous terminal bud; it sends off lateral shoots; it bears secondary roots on its sides and inferior surface, especially on the larger nodes; and it grows annually at the apex while dying away at the base.

The rhizome of Solomon's Seal differs from that of the Mayapple in the following points: it is more fleshy; it is less extensively creeping; its swollen nodes are even more swollen, nearer together, and flattened horizontally; its scale-scars are more crowded and less angular; and the depressed scars on the upper surface are all of one kind, none of them having a bud in the centre; they are, in fact, all stem-scars. There are other minor differences, as those of color, surface, length of rootlets, etc.

So far, however, the differences noted are only such as might occur between rhizomes of closely-related plants. The student must learn that the most important resemblances and differences are not always the ones that are the most obvious. In this instance the differences of greatest significance will be found by studying the internal structure of the bud and the stem.

(2) Now make a drawing of the rhizome about natural size, and point out the following: one of the cup-shaped scars on the upper side of a swollen node; a scale-scar; a bud on one of the lateral branches; the terminal bud; and a root.

II. Internal Structure of the Terminal Bud.—(1) As directed in the former study, divide the terminal bud longitudinally and observe the internal structure. But little difference is seen in the texture and arrangement of the scales, but close scrutiny of their structure shows that the venation is of the parallel or nerved type, while in the scales of the Mayapple a network is distinctly visible. This difference is significant, for nearly all monocotyls have parallel-veined leaves, while nearly all dicotyls have reticulate or netted ones.

In the interior of the bud of Solomon's Seal, as in that of the Mayapple, is to be found, packed away in small compass, the shoot of the coming season. In this case the shoot consists of a tolerably well-formed leafy stem with numerous alternate, two-ranked leaves having minute flower-buds already formed in their axils. The difference between the venation of these true leaves and those in the bud of the Mayapple is still more conspicuous than in the case of the scales—a fact which will be better understood when more particular study is given to leaves.

Note that here also, in the axils of some of the outer bud-scales, on the lower side of the rhizome, is a minute bud whose function it is to continue the underground growth while the above-ground stem and its leaves and flowers are developing.

(2) Make a careful drawing of the bud-section, magnified two or three diameters, and point out the following parts: a bud-scale; the enclosed stem; and the bud that continues the growth of the rhizome.

III. Internal Structure of the Rhizome.—(1) Make three different cross-sections, preferably between the large nodes, and treat one with the phloroglucin reagent, another with iodine

solution, and the third with ferric-chloride solution. Neither of these reagents gives very decided reactions, showing that the structure possesses little if any lignified tissue, that starch is either absent or present only in very minute quantity, and that the same is true of tannic matters. The case is not unusual. Many stems show no tannin reactions; starch, though a very important food-substance, is by no means always present, even in organs which, like this, are heavily charged with food-materials, but is replaced by some similar carbohydrate, as inulin, sugar, etc.; and in fleshy organs such as this lignified cells are seldom abundant, and are quite frequently absent altogether. Vasal or so-called wood-bundles are, however, present in this rhizome, as they are in that of the Mayapple and in the stem of the Hickory. Their distribution, though, is wholly different; in fact, this is one of the most characteristic differences between monocotyls and dicotyls.

Examining closely the iodine-treated section, there will be observed, scattered without order through the section, a considerable number of dots, distinguishable from the adjacent tissue by their somewhat browner color. True, the dots do not come quite to the periphery of the section, there being a narrow zone next the exterior where few or none are found, but within this zone they are numerous and scattered without apparent order, as shown in the diagram, Plate V. (Fig. 3). These dots are the vasal bundles. The zone exterior to them—the blank area *a* in the figure—is the cortex, forming a region in the stem which is analogous to the middle bark and epidermis of the dicotyl. The part within, containing the bundles, is the central cylinder. Not infrequently, though not in this stem, a sheath of woody tissue separates the one zone from the other. This when present is called the *cylinder-sheath*. The bundles are commonly more crowded next this sheath than they are farther interior. As in the Mayapple, they are bundles of stringy tissues running lengthwise of the stem, but they are destitute of cambium, and so, of course, such stems do not possess a cambium zone. These differences apply in the main to the two great groups of plants which they represent. Let these differences be grasped firmly: A dicotyl stem has a three-layered bark, separated from the wood by a cambium zone; the vasal bundles are arranged radially about a central pith, and are separated from each other laterally by

medullary rays; and such a stem increases in thickness by growth in the cambium zone, some of the newly-formed cells adding to the thickness of the wood on its exterior and to the inner bark on its interior. On the other hand, a monocotyl stem has no distinct bark and no cambium zone; its vasal bundles are not arranged in a circle, but scattered through the central cylinder; there are no medullary rays; and, although the centre of such a stem is usually softer than the exterior, there is no proper pith.

The two groups may therefore nearly always be distinguished by merely inspecting cross-sections of their stems, and it makes little difference whether the stems selected for the purpose be above-ground or subterranean ones.

This general rule, however, has a few exceptions. A curious instance in point is the above-ground stem of the Mayapple. The bundles which form a circle in the rhizome send off numerous branches which, rising into the above-ground stem, become scattered irregularly through it, instead of preserving their radial arrangement, so that this stem closely resembles in structure a monocotyl.

In a few other plants the stems exhibit a structure somewhat intermediate between the two types, possessing characteristics of both.

(2) Make a diagram of the cross-section of the stem of Solomon's Seal, magnified three or four diameters, and point out the following: the cortex; the boundary between cortex and central cylinder; a rootlet, if present; and one of the vasal bundles.

The cross-section of the root of the same plant shows a structure quite different from that of the stem. Instead of many scattered small bundles, it has a single large central one, which shows a radial structure of its elements, and is surrounded by a sheath, as shown on Plate V. (Fig. 4). *a* is a root-hair; *b*, the cortex; *c*, the bundle. These differences are usual between the stems and the roots of monocotyls, so that, by examining the structure of a small fragment, the root may easily be distinguished from the stem. These differences will be considered more fully hereafter, when the study of the microscopic structure of roots and stems is reached.

Now study, describe, and illustrate one of the other monocotyl rhizomes mentioned at the beginning of this exercise.

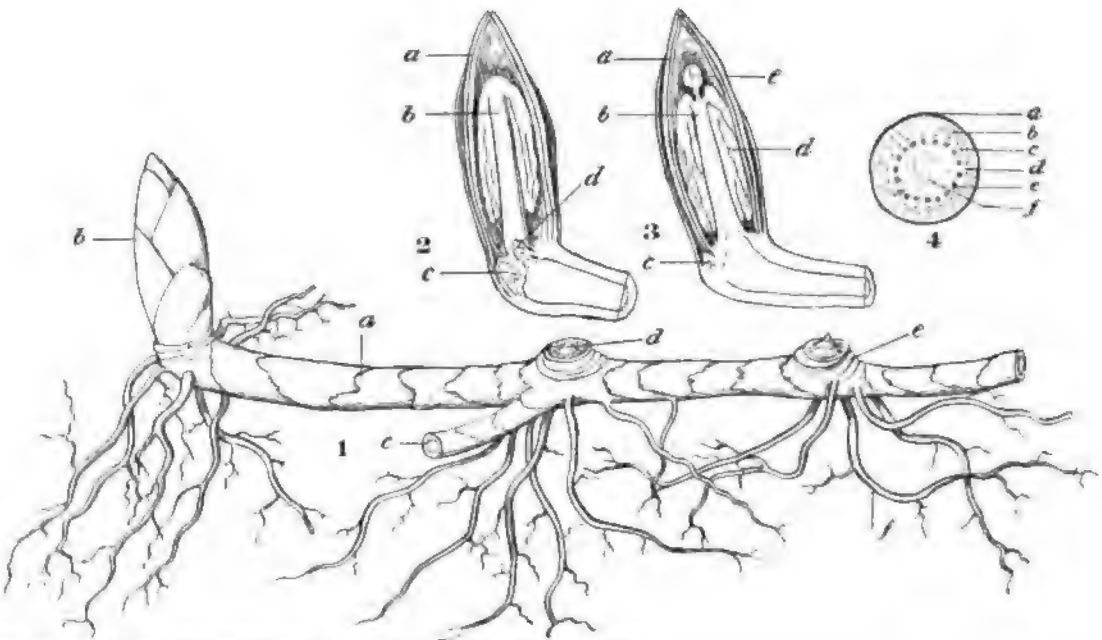


PLATE IV., FIG. 1.—Drawing (about 2/3 natural size) of the Anterior Portion of a Rhizome of Podophyllum peltatum: *a*, a scale-scar; *b*, the terminal bud; *c*, a branch; *d*, a circular leaf-scar; *e*, ring-like scale-scars.

FIG. 2.—Drawing of Vertical Section of Leaf-bud of same Plant (magnified about 2 diameters): *a*, bud-scale; *b*, petiole of leaf; *c*, bud for continuing growth of rhizome; *d*, bud underneath petiole of leaf.

FIG. 3.—Drawing of Vertical Section of another Terminal Bud of same Plant, containing undeveloped stem, leaves, and flower: *a*, bud-scale; *b*, young stem; *c*, bud for continuing growth of rhizome; *d*, true leaf. (The magnification is the same as that of the preceding figure.)

FIG. 4.—Diagram of Transverse Section of Rhizome (magnified about 3 diameters): *a*, corky or outer layer of bark; *b*, middle bark; *c*, bast; *d*, medullary ray; *e*, xylem of a bundle; *f*, pith.

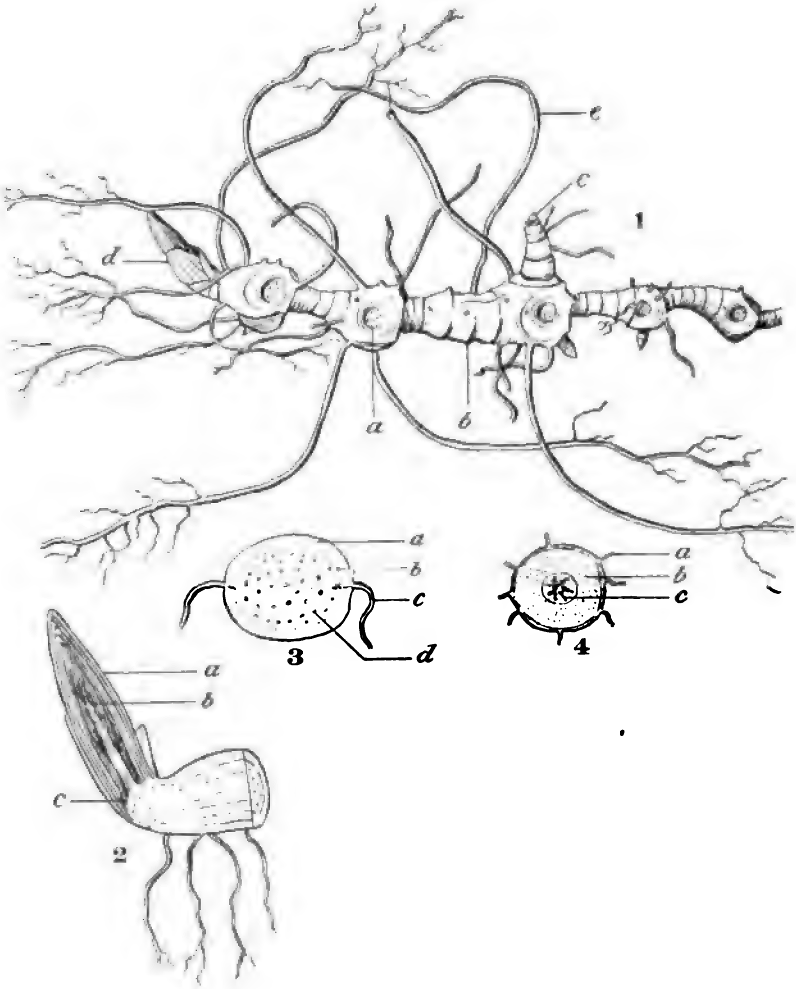


PLATE V., FIG. 1.—Drawing of Rhizome of Polygonatum biflorum (about ⅗ natural size): *a*, cup-shaped stem-scar on upper surface of enlarged node; *b*, scale-scar; *c*, bud on lateral branch; d, terminal bud; *e*, adventitious root.

FIG. 2.—Drawing of Vertical Section of Terminal Bud (enlarged about 1½ diameters): *a*, bud-scale; *b*, young stem within the bud, bearing undeveloped leaves and flower-buds; *c*, bud serving to continue underground growth of rhizome.

FIG. 3.—Diagram of Cross-section of Rhizome (enlarged about 2 diameters): *a*, cortex; *b*, boundary between cortex and central cylinder; *c*, rootlet; *d*, one of the vasal bundles.

FIG. 4.—Diagram of Cross-section of Root (magnified about 7 diameters): *a*, root-hair; *b*, cortex; *c*, central radial bundle enclosed in the bundle-sheath.

EXERCISE V.

STUDY OF STEMS: THE TUBER.

THE following plants afford good studies: The Potato (Solanum tuberosum, *L.*), the Jerusalem Artichoke (Helianthus tuberosus, *L.*), the Indian Cucumber-root (Medeola Virginiana, *L.*), the Toothwort (Dentaria laciniata, *Muhl.*), the Spring Beauty (Claytonia Virginica, *L.*), the Ground-nut (Apios tuberosa, *Moench.*), the Monkshood (Aconitum Napellus, *L.*), the Madeira Vine (Boussingaultia baselloides), and the Crosnes (Stachys tuberifera, *Naudin*).

The most easily procurable of these, as well as one of the best for the purpose, is the Potato. If, before the potatoes are ripe in the autumn, one of the plants be dug up carefully, breaking the underground parts as little as possible, it will be observed that the tubers are borne at the ends of slender underground branches which are sent out in abundance from the subterranean portions of the true stem. Examining these branches with care, scales will be discovered upon them. They are therefore also stems—in fact, rhizomes—such as we have already studied, and the tubers they bear at the ends are really only excessively thickened portions of this rhizome. A tuber, therefore, is only a stem still further modified and disguised, and on giving it close inspection it will be found that, despite its distorted form, it possesses all the essential characteristics of an ordinary stem.

I. EXTERNAL CHARACTERISTICS.—(1) *Axillary Buds.*—The tuber has these buds, the same as an ordinary stem. This is the nature of the so-called "eyes." Examining one of these with care, there will be found in the bottom of each depression one or more—usually several—very imperfectly developed buds, destined, when growth takes place, to form the "sprouts" or true stems. The largest one of the cluster is the axillary bud, and the others, arranged about it, are supernumerary. Many a boy who has had to "sprout" potatoes in his father's cellar

has learned that after the first set of sprouts have been removed others spring from near the same place, so that the tedious operation may have to be repeated. The first set of sprouts are from axillary, the others from supernumerary, buds.

(2) *Leaf-scars.*—Just below this cluster of buds may be seen a transversely elongated scar with a minute scaly point at its middle. This point, rudimentary as it is, really represents a leaf. It is a leaf which has wholly lost its functions and is on the verge of disappearance altogether. This is a good illustration of a not uncommon fact in the organic world. There are few of the higher plants or animals that do not show in some portion of their structure a rudimentary organ wholly useless or perhaps even more or less injurious to its possessor, yet highly significant to the student as showing the relationships of the organism or indicating the course of its descent from pre-existing organisms. So in this case these leaf-scars show unmistakably that the organ which bears them is a stem, and not a root, and that this stem was probably modified or specialized from one of the ordinary forms, thus suiting it to new functions. What these functions are is evident from the study of the habits of the plant. The above-ground parts, and even the roots, perish in the autumn, but the tubers, each stored with abundant nutriment, persist and give rise to a multitude of new plants the succeeding year. The tubers are stems specially adapted to the propagation of the species.

(3) *Terminal Bud.*—But there are other resemblances between this and an ordinary stem which must not be passed by. It has a lower or basal end, and an upper or apical one. At the former will be found the scar of its attachment to the thin rhizome on which it was borne. At the opposite end will be noted a terminal bud, as in other stems. This bud does not differ essentially in structure from the axillary ones, save that it is not subtended by a scale, and is apt to be stronger than they, and therefore to be capable of a more vigorous growth. Partly because of this fact, and partly because the axillary buds are more numerous and stronger toward this than toward the basal end, this end of the potato is often called the "seed end."

The greater development and the crowded character of the buds toward the apex are other points of resemblance between this tuber and most ordinary stems.

(4) *Phyllotaxy.*—Here, again, stem-characters are clearly shown, but to study the phyllotaxy successfully it is necessary that a tuber should be selected which is not too distorted and irregular in its growth. Having made the proper selection, inspection will disclose the fact that the "eyes" appear in spirals, as shown on Plate VI. (Fig. 1), where, to render the fact still more evident, they are connected by dotted lines. This renders it certain that the arrangement is orderly and definite, though by the usual method it might be somewhat difficult to determine the precise phyllotaxy. This can, however, easily be ascertained by the aid of the spiral lines shown. Several sets of spirals might be traced, some running nearly horizontal, others nearly perpendicular, and some passing from right to left, others from left to right. For this purpose there must be selected two sets, one including those spirals nearest the perpendicular which pass from left to right, and the other including those nearest the perpendicular which pass from right to left. Counting the number of spirals in each direction, it will usually be found that there are three of one and five of the other. The smaller number, three, gives the numerator of the fraction expressing the phyllotaxy, and the sum of the two numbers, eight, gives the denominator. The phyllotaxy is therefore three-eighths. The same method is applicable to other short stems on which the leaves or scales are much crowded—as, for example, to the cones of the pines and firs.

II. Internal Structure.—(1) *Arrangement of Tissues.*—Making a cross-section through the tuber in such a manner that it will pass through one of the axillary buds, the following facts will be observed:

First, a rather distinct circle of dots (as shown at *c*, Pl. VI. Fig. 2) a considerable distance within the margin of the section, except where the bud occurs; here, however, the circle approaches the margin and passes into the bud. Each one of these dots really represents the outer end of a wood wedge, each homologous with the ones observed in the Hickory twig, but here possessing but little lignified matter. Immediately outside this circle is the cambium zone.

Secondly, there will be observed, interior to this, scattered dots which are really fragments of the inner portions of the same bundles. These dots, it will be noted, do not occur all through the

interior, but there is an area of greater or less size that is free from them—the pith (*f*, Pl. VI. Fig. 2), and from this outward may be traced many curved and more or less irregular branches which separate the bundles above referred to. These are the medullary rays. One of them is shown at *k* on Plate VI.

Thirdly, in the bark—that is, in the region outside the cambium zone above referred to, and about midway between it and the outside—will be found another circle of dots, fainter than the first, shown at *d* on Plate VI. These dots constitute the outer portion of the bast, and their outer limit marks that of the inner layer of the bark, or endophlœum. From this to the brownish exterior layer is the mesophlœum, and the exterior brownish, corky layer is the exophlœum.

It will thus be seen that in its essential features the internal structure of this stem agrees with that of other stems, and particularly with that of the Hickory and other dicotyl plants. It is, in fact, modified from the type only so much as is necessitated by its very succulent habit.

(2) *Tests.*—Applying the phloroglucin test, there will be found, as might be expected, very little lignified tissue. There are faint indications of it in the row of dots at *c*, and, if these could be examined with the compound microscope, it would be found that the cells which show this reaction are ducts—large tubes formed of coalesced cells found in wood.

The iodine test shows great abundance of starch. It is this substance which gives to the tuber its chief value and causes it to be so extensively employed for food. It is this also which nourishes the buds and enables them to develop into new plants when the tuber is planted. The starch-grains of the potato are unusually large, and can readily be seen with a magnifying-glass, appearing as glistening white particles.

If the test be applied with care, it will readily be seen that the starch is not quite equally distributed through the tuber. It is a little less abundant next the corky outside than it is farther interior. Here, in fact, albuminous matters are abundant, while starch is small in quantity. The reverse is the case with the interior cells. These facts are worthy of consideration in the preparation of the potato for food.

Applying the ferric-chloride test, it will be found that a faint

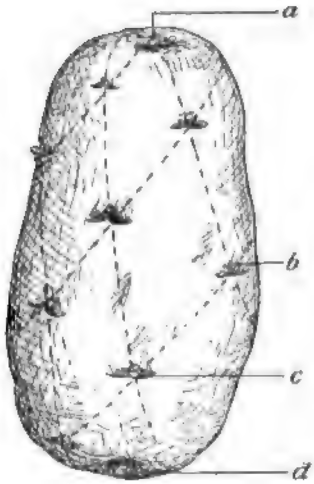
green color is produced in the section, showing that tannic matters are present. This accounts for the tarnishing of a bright knife-blade when used for paring the tubers, the tannin acting upon the iron to produce tannate of iron.

Another fact worthy of note in connection with the potato tuber is that, when exposed for some time to strong light, it becomes green. This is due to the development of chlorophyll in the cells of the mesophlœum; but accompanying this change is the development of a poisonous principle which communicates an acrid taste to the tuber even when cooked. Cattle, in fact, have been poisoned by feeding upon potatoes which have turned green by exposure.

The above-ground green parts of the potato plant contain poisonous matter also, and it is worth remembering that the family to which the plant belongs—the Solanaceæ—contains many of the most dangerous of the vegetable poisons, as belladonna, stramonium, and hyoscyamus.

The student should now make a parallel study of one or more of the other tubers mentioned at the beginning of this exercise.

1



2

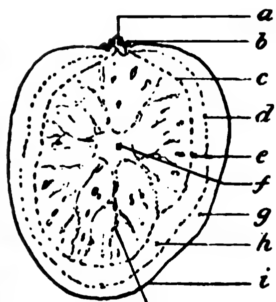


PLATE VI., FIG. 1.—Tuber of Solanum tuberosum (⅔ natural size), showing, *a*, terminal bud; *b*, axillary bud; *c*, one of the scales subtending an axillary bud; *d*, scar where tuber was attached to underground shoot.

FIG. 2.—Transverse Section of Tuber (⅔ natural size): *a*, one of the axillary buds; *b*, a supernumerary bud; *c*, one of the circle of dots, the outer part of the xylem of one of the bundles; *d*, one of the circle of dots, the outer part of the bast or phloem of a bundle; *e*, cambium; *f*, pith; *g*, mesophlœum; *h*, endophlœum; *i*, exophlœum; *k*, one of the medullary rays.

EXERCISE VI.

STUDY OF STEMS: THE CORM.

THE following afford good examples for study: Gladiolus (G. communis, *L.*, or G. psittacinus), Crocus (C. vernus, *Willd.*, or C. sativus, *L.*), Colchicum (C. autumnale, *L.*), Indian Turnip (Arisæma triphyllum, *Torr.*), Green Dragon (Arisæma Dracontium, *Schott*), Calladium (C. esculentum).

The first in this list is selected, as the corms are easily procurable and are very typical in their structure. Here, as in the rhizome, is to be found a stem in disguise, only it is disguised still more effectively. It is, in fact, a broad, thick, erect rhizome covered with thin dry scales.

I. EXTERNAL CHARACTERISTICS.—(1) *The Scales and Buds.*—Remove these scales one by one, observing their structure and mode of insertion. They are brown and veiny, with the veins parallel below and becoming somewhat netted toward the top, where they are also shreddy; they are inserted one above the other on the corm, and not on one side only, but all the way around; when they are removed they show a succession of circular scars one above the other. Just above each scar will usually be seen a bud, and these buds appear in alternate order, forming two ranks, showing that the scales really have the one-half arrangement, as is the fact with the true leaves of the same plant and of other plants of the same family, the Iridaceæ.

It will be observed that, as in many ordinary stems, the lower axillary buds are minute and very imperfectly developed, those higher up being successively larger, and the terminal bud being largest of all. During the growing season the lateral buds may give rise to new corms—another means, besides the seeds, of multiplying the plants.

(2) *The Stem.*—Aside from the buds, what is left, after removing the scales, is the main stem, a thick fleshy mass which bears little semblance to an ordinary stem, but which certainly is one,

because it bears leaf-scales and axillary buds. Its surface is punctate with numerous depressed points, and is also distinctly furrowed longitudinally. The lower or rooting end is deeply depressed, and the terminal bud arises from a similar deep depression in its upper or apical end. Aside from these depressions, however, the corm is usually nearly twice as broad as high. The lower end gives rise to numerous nearly simple adventitious roots.

If now the corm be cut transversely into two nearly equal portions, two regions are clearly distinguishable: a central cylinder region, in which there are numerous scattered vasal bundles, and which is more or less angular in its outline, and a thick cortical region which exudes a copious yellow milk-juice and which is crossed by occasional bundles. Toward its periphery also it is dotted with cells containing red or other coloring-matter.

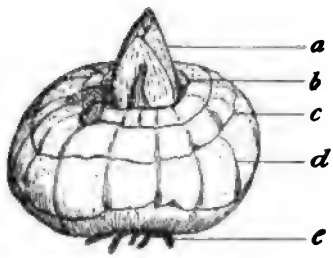
The few scattered bundles found in the cortex are those which pass out from the central cylinder to supply the leaves and buds. Aside from this unusual thickness of the cortex, the stem-structure is clearly like that of other monocotyls which have been studied.

(3) *Tests.*—Applying the phloroglucin test, there will be found, as in other succulent stems, but little lignified tissue, and that confined to the vasal bundles.

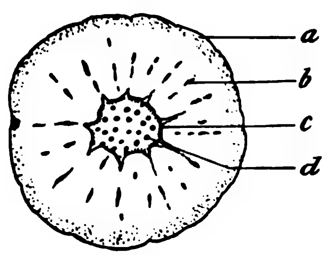
Applying the iodine test, abundance of starch will be found. The parenchyma cells, particularly those of the cortex, are, in fact, well filled with it.

The ferric-chloride test also reveals the presence of tannic matters, both in the outer cortex and in the vicinity of the cylinder-sheath, and also within the latter.

Let, now, one or more of the other corms mentioned at the beginning of this exercise be studied and described by the student.



1



2

PLATE VII., FIG. 1.—Corm of Gladiolus (about ¾ natural size), deprived of its outer covering of scales: *a*, terminal bud: *b*, axillary bud; *c*, scar of one of the scales; *d*, one of the longitudinal furrows; *e*, adventitious root.

FIG. 2.—Transverse Section of same Corm: *a*, outer cortex dotted with cells containing coloring matter; *b*, one of the vasal bundles on its way through the cortex from the central cylinder to supply a scale; *c*, cylinder-sheath; *d*, one of the vasal bundles in the central cylinder.

EXERCISE VII.

STUDY OF STEMS: THE BULB.

FROM the following list selections for study may be made: (1) *Scaly bulbs:* The White Lily (Lilium candidum, *L.*), the White Japan Lily (Lilium Japonicum, *Willd.*), the Tiger Lily (Lilium tigrinum, *Ker.*), the Wild Orange-red Lily (Lilium Philadelphicum, *L.*), the Wild Yellow or Canada Lily (Lilium Canadense, *L.*), the Violet Wood-sorrel (Oxalis violacea, *L.*). (2) *Tunicated bulbs:* The St. James Lily (Amaryllis formosissima, *Willd.*), the Atamasco Lily (Amaryllis Atamasco, *L.*), the Onion (Allium Cepa, *L.*), the Garlic (Allium sativum, *L.*), the Wild Onion (Allium cernuum, *Roth.*), the Wild Hyacinth (Camassia Frazeri, *Torr.*), the Common Hyacinth (Hyacinthus orientalis, *L.*), the Adder's Tongue (Erythronium Americanum, *Ker.*), the Daffodil (Narcissus Pseudonarcissus, *L.*), and the Snowdrop (Galanthus nivalis, *L.*).

The study may be divided into two parts, the scaly bulb being first taken up, and afterward the tunicated one.

I. THE SCALY BULB OF LILIUM CANDIDUM.—This bulb is easily procurable and is typical of its kind.

(1) *How it Differs from a Corm.*—Like the latter, and like the tuber and rhizome, it is an underground stem. In shape it also much resembles the corm, and, like it, is surcharged with nutritious matters. But a very obvious difference is the fact that in this the scales are succulent and heavily charged with nutritious matters, while in the corm they are thin and scarious, the nutriment being almost wholly stored in the fleshy axis.

(2) *Nature of the Scales.*—These fleshy scales bear even less resemblance to ordinary leaves than do corm- or bud-scales, and yet it is obvious that they must be regarded as modified leaves, for, in the first place, they have the same orderly arrangement, and their phyllotaxy might even be determined in the same way as was done in the case of the potato; and, in the second place, they,

occasionally at least, bear buds in their axils in the same manner as do ordinary leaves. Still further evidence, if any were needed, could be found by tracing the gradations between the outer or lower scales and the inner or upper ones. The latter develop into true leaves, while the former do not, and yet they grade insensibly one into the other.

(3) *Likeness of a Bulb to a Bud.*—A bud has been defined as a very short axis on which imperfectly-developed leaves are compactly arranged. If a longitudinal section through the lily-bulb be made, it will be seen how closely this definition applies to the bulb. Buds may, in fact, under certain conditions become bulbs. For example, the Tiger Lily of the gardens bears axillary buds which are precisely similar to ordinary axillary buds except that the scales in development become fleshy, and after a time the buds separate from the plant and fall to the ground. Each one of these, when planted in the soil, becomes a bulb essentially like the one being studied. Such fleshy buds, or *bulbils*, as they are technically called, are also produced by other plants, notably by different species of the genus Allium, and they are efficient means of propagating the species.

(4) *The Roots.*—The bulb-axis shows its resemblance to other stems not only in the fact that it bears leaves, but also in the fact that it bears roots. In this instance the roots are of the fibrous variety and numerous, and it may easily be seen that they arise laterally from the stem and are not downward continuations of it. In fact, they may often be found originating above some of the lower scale-scars. They are therefore adventitious roots.

(5) *Venation of Scales.*—Studying carefully the surface of the scales, and examining cross-sections of them, it will easily be determined that the venation is parallel, or the kind that usually occurs in monocotyl plants, the group to which the Lily belongs.

(6) Making a cross-section of the stem, there will also be observed the same scattered arrangement of the vasal bundles that belongs to the stems of monocotyls.

II. THE TUNICATED BULB OF AMARYLLIS FORMOSISSIMA.—This might at first be taken for a corm, to which it bears a greater external resemblance than it does to the Lily bulb. This mistake will be corrected, however, when a longitudinal section of the bulb is made and its structure is studied. It will now be found

that, as in the Lily bulb, the great bulk is composed of fleshy scales, and these are also inserted on a short, inconspicuous axis.

(1) *Why called Tunicated.*—The most conspicuous difference is in the arrangement of the scales. Each is a leaf whose attachment to the stem extends all the way around, and each leaf in succession encloses and conceals from view all those interior to it or inserted higher up on the axis. They form thus a succession of coats, one within the other; hence a bulb of this kind is called a *coated* or *tunicated* bulb, to distinguish it from one like that of the Lily, which is termed *scaly.*

(2) *Kinds of Scales.*—Another difference is observed. The exterior dark-brown or blackish scales are dry or scarious, and serve purely a protective purpose, while the interior colorless ones are used, like those of the Lily, as storehouses for food.

In the Amaryllis also, even more easily than in the Lily, can be traced the relations between the scales and ordinary leaves. Many of the interior scales may, indeed, be traced directly upward into true leaves. They are, in fact, leaf-bases.

The scales are all distinctly parallel-veined, and the stem shows the characteristic structure of monocotyl stems.

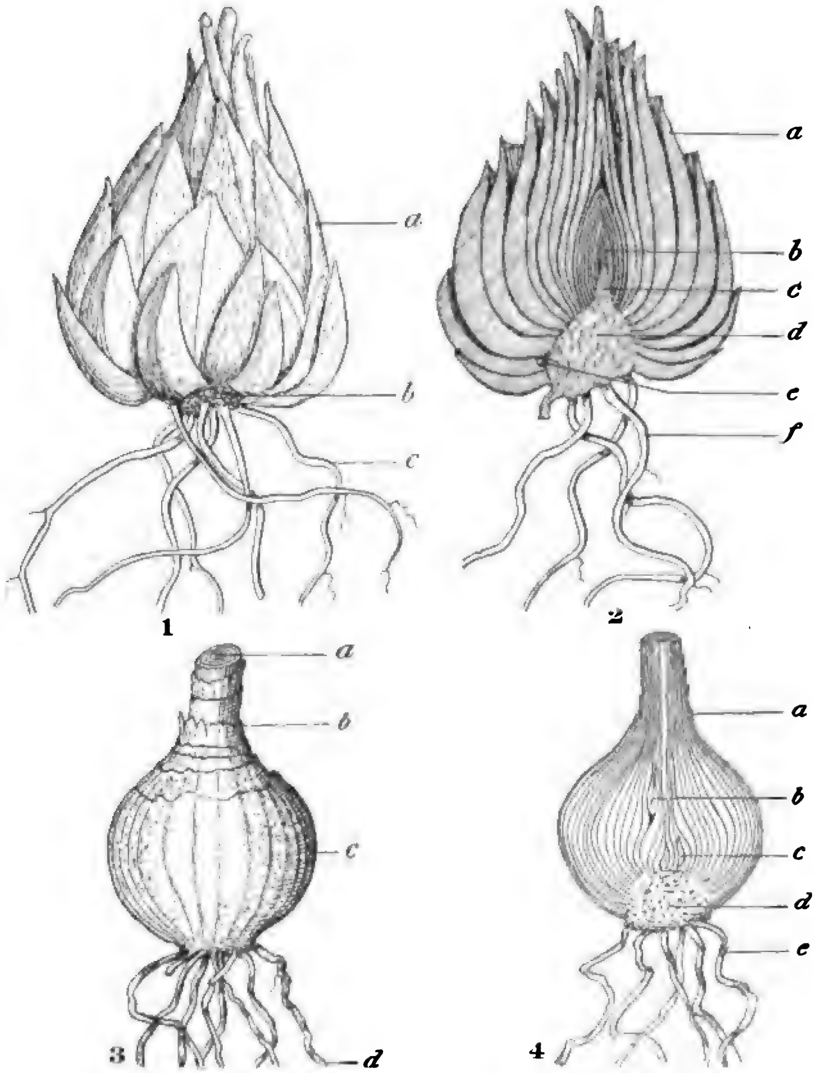


PLATE VIII., FIG. 1.—Drawing (½ natural size) of bulb of Lilium candidum: *a*, one of the bulb-scales; *b*, lower or exposed part of the stem or axis; *c*, an adventitious root.

FIG. 2.—Longitudinal Section of the Bulb of Lilium candidum (½ natural size): *a*, one of the succulent scales; *b*, one of the imperfectly developed true leaves; *c*, imperfectly formed stem, destined to rise above ground and to bear leaves and flowers; *d*, bulb-axis; *e*, axillary bud; *f*, adventitious root.

FIG. 3.—Bulb of Amaryllis formosissimum (⅔ natural size): *a*, section of leaves concentrically arranged; *b*, frayed upper margin of one of the scales; *c*, one of the exterior, dry scales; *d*, an adventitious root.

FIG. 4.—Longitudinal Section of the same: *a*, one of the outer, dry scales; *b*, section of one of the axillary buds; *c*, section of another axillary bud; *d*, the bulb-axis, showing numerous scattered fibro-bundles; *e*, an adventitious root.

FORM FOR STUDY OF STEMS.

I. KIND.
  1. *Aërial.*
    (1) Caulis.
    (2) Caudex.
    (3) Culm.
    (4) Scape.
    (5) Tendril.
    (6) Runner.
    (7) Sucker.
    (8) Offset.
    (9) Stolon.
    (10) Thorn.
    (11) Cladophyll.
  2. *Subterranean.*
    (1) Rhizome.
      Slender.
      Fleshy.
    (2) Tuber.
    (3) Corm.
    (4) Bulb.
      Scaly.
      Tunicated.

II. SHAPE.
  1. Terete.
  2. Flattened.
  3. Alate.
  4. Triquetrous.
  5. Quadrangular.
  6. Pentangular.
  7. Fluted.
  8. Solid.
  9. Hollow.
  10. Irregular.
  11. Jointed.

III. DIRECTION AND HABIT.
  1. Erect.
  2. Ascending.
  3. Reclinate.
  4. Decumbent.
  5. Procumbent.
  6. Repent.
  7. Voluble.
  8. Scandent.

IV. SURFACE.
  1. Glabrous.
  2. Glaucous.
  3. Glandular.
  4. Rugose.
  5. Scabrous.
  6. Verrucose.
  7. Pubescent.
  8. Puberulent.
  9. Sericeous.
  10. Lanuginous.
  11. Tomentose.
  12. Villose.
  13. Pilose.
  14. Floccose.
  15. Hispid.
  16. Strigose.
  17. Spinose.
  18. Echinate.
  19. Aculeate.
  20. Annulate.
  21. Channelled.
  22. Fissured.
      Transversely.
      Longitudinally.

V. TEXTURE.
  1. Succulent.
  2. Woody.

VI. DURATION.
  1. Herbaceous.
      Annual.
      Biennial.
      Perennial.
  2. Suffruticose.
  3. Fruticose.
  4. Arborescent.
  5. Arboreous.

VII. FRACTURE.
  1. Short.
  2. Brittle.
  3. Splintery.
  4. Fibrous.
  5. Horny.
  6. Corky.
  7. Mealy.
  8. Friable.

VIII. CLEAVAGE.
  1. Regular.
  2. Irregular.
  3. Difficult.
  4. Easy.

IX. COLOR.
  1. Exterior.
  2. Interior.

X. TASTE.
  1. Insipid.
  2. Bland.
  3. Sweet.
  4. Bitter.
  5. Mucilaginous.
  6. Pungent.
  7. Acrid.
  8. Warm.
  9. Cooling.
  10. Astringent.
  11. Nauseous.
  12. Burning.
  13. Prickling.
  14. Saline.
  15. Alkaline.
  16. Acidulous.

XI. ODOR.
  1. Odorless.
  2. Faint.
  3. Agreeable.
  4. Aromatic.
  5. Fragrant.
  6. Mint-like.
  7. Balsamic.
  8. Camphoraceous.
  9. Terebinthinate.
  10. Pungent.
  11. Musky.
  12. Disagreeable.
  13. Irritating.
  14. Nauseous.
  15. Narcotic.
  16. Fetid.
  17. Putrid.

XII. INTERNAL STRUCTURE.
  1. *Fern type.*
    (1) Cortex.
      a. Thickness compared with that of central cylinder.
      b. Bundles in:
        Numerous.
        Few.
        Lignified.
        Unlignified.
      c. Sclerenchyma-fibres.
    (2) Central cylinder.
      a. Bundles in:
        Numerous.
        Few.
        All in one circle.
        In more than one circle.
        One circle with extra bundles in centre.
        Lignified.
        Unlignified.
    (3) Masses of lignified tissues not a part of the bundles.
    (4) Starch.
      a. Most abundant in cortex.
      b. Most abundant in central cylinder.
    (5) Tannic matters.
      a. Most abundant in cortex.

FORM FOR STUDY OF STEMS (CONTINUED).

- *b.* Most abundant in central cylinder.

2. *Monocotyl type.*
   - (1) Cylinder-sheath.
     - *a.* Distinct.
     - *b.* Indistinct.
     - *c.* Lignified.
     - *d.* Unlignified.
   - (2) Cortex.
     - *a.* Thickness compared with central cylinder.
     - *b.* Bundles in:
       - Numerous.
       - Few.
       - Lignified.
       - Unlignified.
   - (3) Central cylinder.
     - *a.* Bundles in:
       - Numerous.
       - Few.
       - Lignified.
       - Unlignified.
     - *b.* Solid.
     - *c.* Hollow.
   - (4) Starch.
     - *a.* Most abundant in cortex.
     - *b.* Most abundant in central cylinder.
   - (5) Tannic matters.
     - *a.* Most abundant in cortex.
     - *b.* Most abundant in central cylinder.

3. *Dicotyl type.*
   - (1) Cambium zone.
     - *a.* Distinct.
     - *b.* Indistinct.
   - (2) Bark.
     - *a.* Thickness relative to wood.
     - *b.* Layers.
       - Indistinct.
       - Distinct.
       - Relative thickness of—
         - Exophlœum.
         - Mesophlœum.
         - Endophlœum.
     - *c.* Mesophlœum.
       - Stone-cells.
         - Numerous.
         - Few.
     - *d.* Endophlœum.
       - Distinctly radiate.
       - Indistinctly radiate.
       - Not radiate.
       - Bast-masses.
         - Stratified.
         - Unstratified.
         - Shape.
           - Conical.
           - Linear.
           - Oblique.
           - Curved.
         - Bast-fibres.
           - Numerous.
           - Few.
           - Strongly lignified.
           - Slightly lignified.
           - Unlignified.
   - (3) Woody cylinder.
     - *a.* Distinctly radiate.
     - *b.* Indistinctly radiate.
     - *c.* Annulate.
     - *d.* Medullary rays.
       - Narrow.
       - Medium.
       - Broad.
       - Lignified.
       - Unlignified.
     - *e.* Xylem wedges.
       - Narrow.
       - Medium.
       - Broad.
       - Lignified.
       - Unlignified.
     - *f.* Ducts.
       - Conspicuous.
       - Inconspicuous.
       - Numerous.
       - Few.
     - *g.* Fissuring.
       - Fissured.
       - Unfissured or entire.
     - *h.* Pith.
       - Large.
       - Small.
       - Entire.
       - Hollow.
   - (4) Starch.
     - *a.* Most abundant in—
       - Mesophlœum.
       - Endophlœum.
       - Medullary rays.
       - Xylem wedges.
       - Pith.
     - *b.* No starch.
   - (5) Tannic matters.
     - *a.* Most abundant in—
       - Exophlœum.
       - Mesophlœum.
       - Endophlœum.
       - Cambium zone.
       - Medullary rays.
       - Xylem wedges.
       - Pith.
     - *b.* No tannic matters.

EXERCISE VIII.

STUDY OF A LEAF.

THE student has already studied leaves in the form of bud-, bulb-, and corm-scales, and has thus learned that they may assume various disguises. There is, in fact, no other organ of the plant that passes through so many modifications. Leaves may be found changed to spines for defensive purposes, as in the Barberry and Cactus; or in the form of tendrils to serve the plant for climbing, as in the Pea and Vetch; or modified into insect-traps of various kinds, as in Dionœa, Sarracenia, and Utricularia; or changed into the various organs of the flower to subserve the function of reproduction. The leaf will hereafter be studied in several of these disguises, but for the present will be considered in its more typical form, that of a foliage leaf.

Even this assumes a great many different shapes and forms on different plants, and sometimes even several different ones on the same plant; but it is usually a flattened, bilaterally symmetrical organ, having distinct upper and under surfaces.

Leaves, of whatever sort, are outgrowths from a stem. They always occur in regular order upon it, nearly always according to some form of the alternate or of the whorled plan, and in acropetal succession; that is, the oldest leaf is always the lowest down on the stem, the youngest highest up or nearest the apex, every leaf beginning its growth just back of the stem-apex.

Foliage leaves are pre-eminently the digestive organs of the plant. The food is partly brought to them through the stem, and partly taken up by the leaves themselves directly from the atmosphere. They also always possess the green coloring-matter called chlorophyll, although in a few instances this is more or less obscured by the presence of other coloring-matters; and this green matter is essential to the digestive process. By aid of the sunlight chlorophyll is able to bring into combination the elements of the relatively simple mineral substances carbon dioxide and water,

and to make of them a complex organic substance, a carbohydrate, which in turn is employed by the living matter of the plant in building up the tissues, in enlarging the roots, the stems, and the leaves themselves, and in producing flowers and fruit.

The leaf, then, is an organ which, by aid of light, elaborates the plant's food. It is a mechanism which makes use of the force which resides in the sun's rays to do the constructive work of the plant. Leaves, consequently, are usually so constructed and arranged upon the stem as to secure as full exposure to the light as possible. In studying their forms and phyllotaxy it is important to bear this fact in mind. It will help to explain many things.

For this first study of leaves those of any of the following plants may be selected: the Horseshoe Geranium (Pelargonium zonale, *Willd.*), the Quince (Cydonia vulgaris, *Persoon*), the Apple (Pyrus Malus, *L.*), the Bird Cherry (Prunus avium, *L.*), the Black Cherry (Prunus serotina, *Ehrh.*), the Crab-apple (Pyrus coronaria, *L.*), the Hawthorn (Cratægus coccinea, *L.*), the Marsh-mallow (Althæa officinalis, *L.*), the Hollyhock (Althæa rosea, *Cav.*), the Hibiscus (Hibiscus Syriacus, *L.*), the Basswood (Tilia Americana, *L.*), and the Tulip Tree (Liriodendron tulipifera, *L.*).

Selecting for the present purpose the first named in this list, the student will observe—

(1) *The Parts.*—Here are present all the parts which any leaf can possess—namely, an expanded portion, the *lamina* or blade; a stalk-like portion by which the lamina is attached to the stem, called the *petiole;* and, at the base of this latter, two small flattened bodies, one on either side, called the *stipules.* Let these parts be studied in succession.

(2) *The Lamina.*—This consists of different parts, the first to be noted being a framework or system of veins branching out from the top of the petiole and forming a complicated network through the lamina. Holding the leaf up to the light, it will be observed that these veins, though thicker than the intermediate portions of the leaf, are more transparent; they, in fact, contain relatively little chlorophyll. Their function is partly to form a support for the rest of the leaf, partly to distribute to it nutritive matters from the stem; and how admirably it is fitted for both purposes! Secondly will be noted the deep-green filling between

the veins, the most important part so far as the digestive function is concerned. This part is called the *mesophyll.* Lastly, it will be observed that the whole is covered, above and below, by an epidermis which is protective in its function, preventing the too rapid evaporation of the leaf-juices and guarding the delicate interior tissues from the depredations of insects, fungi, etc. Though thin, its cells are tough-walled, compactly arranged, and partially cutinized, the cutin (another name for cork-substance) rendering it highly impermeable to moisture, and so preventing excessive evaporation.

In this case also the epidermis is provided with numerous hairs, some of the ordinary kind, and others glandular, which afford a still further protection against insects.

If a piece of the epidermis be stripped off and held up to the light, it will be found colorless and transparent. The greenness of the leaf is therefore not at all due to the epidermis, but to the chlorophyll particles in the sub-lying cells.

(3) *The Two Surfaces.*—Comparing these, it will be seen that they are by no means alike. First, they differ in depth of color, the upper being of a darker green than the lower surface. This is due to the fact that the chlorophyll-bearing cells of the mesophyll are more compactly arranged and contain more chlorophyll-bodies next the upper surface than next the lower; and this is nearly always the case with those leaves whose two surfaces are not equally exposed to the light. Secondly, the veins stand out prominently on the lower or *dorsal* surface, but are less prominent, or even depressed, on the upper or *ventral* surface. This also is the fact with most leaves, and it enables us in most cases readily to distinguish between the dorsal and ventral surfaces even when the leaves are detached from the plant. Thirdly, a close inspection of the two surfaces under the magnifying-glass shows that the dorsal surface is more abundantly provided with hairs, and that these are longer, particularly on the veins. This also is usually the case where leaves possess hairs at all. In some instances there are none at all on the ventral surface, while the dorsal surface may be densely clothed with them. This is probably because the latter is more in need of protection. If the two surfaces could be examined with a compound microscope, the lower surface would be found to possess numerous *stomata*, or breathing apertures—little doors, so to

speak, which the plant may open to get rid of superfluous moisture, or close to prevent its too rapid escape. These, except in leaves that expose the two surfaces equally to the light, are much the more abundant on the dorsal surface, and are frequently absent altogether from the ventral surface. The former is therefore, unless specially protected, the more vulnerable to insects and germinating fungus-spores.

In this leaf also the upper surface is marked with a peculiar brown horseshoe-shaped band, which has given origin to the popular name of the plant, Horseshoe Geranium. This band is due to the presence of a brownish coloring-matter dissolved in the sap of those mesophyll cells lying adjacent to the upper epidermis, but its use is unknown.

(4) *Shape of the Lamina.*—It is important that leaf-forms should be described with precision. First, we distinguish the *base*, or the end which is attached to the petiole or stem; then the *apex*, or the end opposite the base; and then the *margin*, or the edges between the base and the apex.

In describing the blade it is best first to describe the *general outline;* that is, the outline without regard to the particular form of the base, apex, or margin. In this view the leaf is *round* or *orbicular*. Next describe the base. It is deeply and sharply cleft—a fact which is described by the word *cordate*, or heart-shaped. Next describe the apex, which in this instance is blunt or *obtuse*. Lastly, describe the margin, which is doubly scalloped; that is, there is a set of large scallops, and these again are divided into smaller ones. A scallop-margined leaf would be described as *crenate;* this leaf, being doubly scalloped, is described as *bicrenate*.

(5) *Surface of the Lamina.*—This, as has been seen, is hairy, and, since the hairs are soft, short, and some of them glandular, the surface is described as *glandular-pubescent*. The leaves of different plants differ widely in this respect. Some are *glabrous*, or smooth; some *glaucous*, or covered with an easily removable powder; some are *scabrous*, or rough and harsh to the touch; some are *lanuginous*, or covered with woolly hairs; some are *spinose*, or covered with spiny hairs or prickles; and so on.

(6) *The texture of the lamina* should also be observed and described. Some leaves, as has been seen, are not green, but of some other color, and dry, such as bud-scales, the scales of corms,

and many stipules. Such leaves are called *scarious*, while ordinary green ones are *herbaceous*. Either may be *membranous* (thin and pliable), *coriaceous* (of the texture of leather), or *succulent* (thickened but soft), but it is not often that any but scarious leaves are hard and *woody* in their texture; this, however, is sometimes the case with the leaves of tropical evergreens. The one now being studied is herbaceous and membranous.

[The student should, as soon as possible, become familiar with the terms employed in leaf-description by studying the chapter on "The Leaf" in *College Botany* or in the *Elements of Botany*.]

(7) *The Petiole.*—This in the Geranium is long and cylindrical, or nearly so, though, if examined closely, it will be found to be distinctly channelled on its upper surface near its base or junction with the stem. It is seldom the case that any petiole is wholly destitute of this channel, or, at least, of some flattening on its upper surface, and very commonly the flattening or channelling extends its whole length. We may therefore by this means also tell the dorsal from the ventral surface of the leaf. The petiole has also a distinct enlargement at its base or junction with the stem, called the *pulvinus*.

The petiole of Geranium is, like the blade, covered with a glandular pubescence.

The petiole may undergo a variety of modifications. It may be flattened vertically or horizontally; it may even become thin and blade-like, taking the place of the blade functionally while the latter organ disappears; or it may itself be altogether wanting, in which case, the blade being inserted directly upon the stem, the leaf is described as *sessile*.

(8) *The Stipules.*—These two bodies are much like small blades in texture and appearance. They have a framework of veins, a green mesophyll, and a glandular-pubescent epidermis. They probably perform to some extent the functions of blades, helping to digest the plant-food; but this function in the Geranium is but temporary, for in the older leaves we find them withered and scarious. Their chief use, perhaps, is to protect the remainder of the leaf while in the bud. Indeed, it very often happens that this is their only function, since in many plants they fall away as soon as the buds unfold.

In some plants the stipules are attached by their base to the

base of the petiole; in others they are partly attached to the petiole and partly to the stem; in others still they are partly or wholly adnate to the sides of the petiole, and not infrequently are so blended with it as to have lost their identity, forming a sheathing base to the petiole which partially or wholly clasps the stem; and, lastly, in a few plants the two stipules not only grow fast to the petiole by one edge, but adhere to each other by the other edge, forming a sheath or *ochrea* about the stem. They are also sometimes modified into thorns or tendrils or honey-glands, and in many plants are wanting altogether.

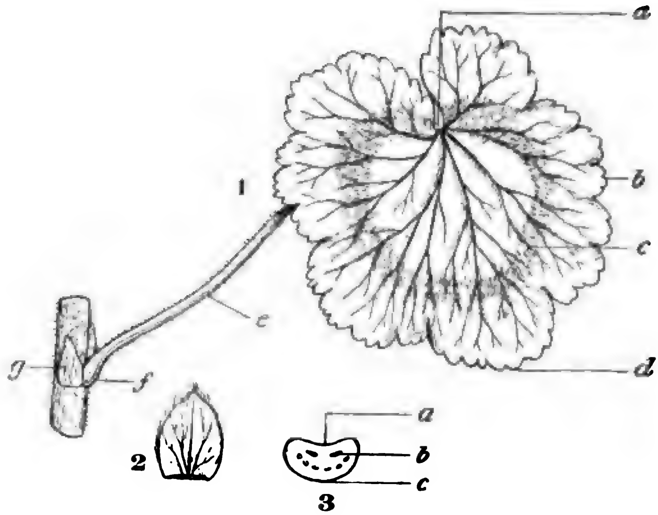


PLATE IX., FIG. 1.—Leaf of Pelargonium zonale (⅔ natural size): *a*, cordate base; *b*, bicrenate margin; *c*, dark-colored zone on upper surface; *d*, obtuse apex of blade; *e*, petiole; *f*, pulvinus, or enlarged base of petiole; *g*, one of the stipules.

FIG. 2.—A Stipule separated (about natural size).

FIG. 3.—Somewhat magnified Cross-section of Petiole through Pulvinus: *a*, channelled upper surface; *b*, one of the vasal bundles; *c*, convex lower surface.

EXERCISE IX.

STUDY OF PREFOLIATION.

THE following plants afford variety and interest from this standpoint: the Beech (Fagus ferruginea, *Ait.*), the Tulip Tree (Liriodendron tulipifera, *L.*), the Azalea (Rhododendron arborescens, *Torr.*), the Cherry (Prunus avium, *L.*), the Clover (Trifolium pratense, *L.*), the Violet (Viola palmata, *L.*, var. cucullata, *Gray*), the Shield Fern (Aspidium acrostichoides, *Swartz.*), the Royal Fern (Osmunda regalis, *L.*), the Yellow Dock (Rumex crispus, *L.*), the Blue Flag (Iris versicolor, *L.*), the Water-Lily (Nuphar advena, *Ait.*).

The term "prefoliation" has reference to the arrangement of leaves in the bud; not to their phyllotaxy, which has already been explained, but to the coiling, folding, or overlapping of the leaves.

Prefoliation may be considered in two aspects: first, with reference to the *individual leaf*—how it is bent, folded, rolled, etc.; or with reference to the relative arrangement of the leaves composing a whorl or cycle—whether they overlap or not, and, if they do, what is the manner of the overlapping. The subject is best studied in early spring when the buds begin to unfold.

For the first study let the bud of the Beech be selected.

(1) *Prefoliation of Beech.*—The mature leaf is illustrated on Plate X. (Fig. 1), and the young leaf, just issued from the bud, but not yet fully unfolded, is shown on Plate X. (Fig. 2). In the latter the scarious and deciduous stipules are seen still attached to the base. They have served their purpose as bud-scales, and are now about to disappear. A careful inspection of this young leaf-blade shows that the two sides have each been thrown into numerous regular parallel folds, one for each rib of the leaf, and these folds have been pressed closely upward against the midrib—a mode of prefoliation which is appropriately called *plicate*. By this arrangement the young leaf is made to occupy a relatively small space in

the bud, and even this space is still further diminished by an inward curvature of the edges which renders the inner or ventral surface somewhat trough-shaped. The leaf is therefore also somewhat *involute.* Into this concavity fits closely the convex side of the next higher and somewhat smaller leaf in the cycle, and so on.

An examination of the arrangement discloses the fact that Nature has done a wonderfully skilful piece of packing in the construction of the bud. The study also enables one to account for the gracefully elongated form of the buds.

But Nature does not always accomplish her results by the same methods. There is an endless variety both in methods and results. A different but scarcely less interesting prefoliation is seen in the Clover.

(2) *Prefoliation of Clover.*—Figure 3 (Pl. X.) represents a branch of Trifolium pratense with two leaves fully developed, and another just emerging from the bud, and not yet unfolded. It will be observed that each leaf consists of a ternately compound blade, a long petiole, and a pair of adnate stipules. These last, as is true of most stipules, play an important part in the prefoliation.

Examining now the blade of the youngest of the three leaves in the figure, it will be perceived that each leaflet is folded lengthwise on its midrib in such a manner that the ventral surface is interior and that the three leaflets are pressed close together side by side. The arrangement will easily be understood by reference to Plate X. (Fig. 4), which shows the same leaf removed from the plant and having its leaflets slightly separated from each other.

Before their emergence from the bud their relative arrangement and folding were the same, but the blade was much smaller and wholly enclosed by the two stipules of the leaf immediately below. In fact, on Plate X. (Fig. 4) the stipules (*a*) are wrapped about and conceal a still younger leaf, which is folded as already described, but whose edges face in the opposite direction. This is called the *conduplicate* mode of prefoliation, and, although quite different from the last, serves the purpose of compactness equally well. A third and quite different mode still is that illustrated in the Yellow Dock.

(3) *Prefoliation of Yellow Dock.*—Figure 5 (Pl. X.) also shows a branch with two nearly mature leaves and one, younger, not yet

unfolded. The leaves here consist of a long lanceolate blade having a toothed and crispate margin, a strongly-developed petiole which is flat on its upper surface and convex below, and stipules which have coalesced to form a membranous ochrea which continues to enclose the younger leaves even until the latter have attained a length of an inch or more, when the ochrea ruptures and scales off. Each of these young leaves is rolled from its two margins in such a manner that the dorsal or lower surface is interior. This mode of prefoliation is called the *revolute.*

Figure 6 (Pl. X.) represents two of the young leaves as they appear in transverse section, slightly separated from each other and partly unrolled. As a matter of fact, in the bud the leaves are very closely rolled, and the flattened upper surface of the rolled leaf lies close against the flat upper side of the petiole of the next older leaf.

The student by studying the other plants mentioned at the beginning of this exercise will get a good idea of all the principal modes of prefoliation, though there are endless variations in detail in different plants.

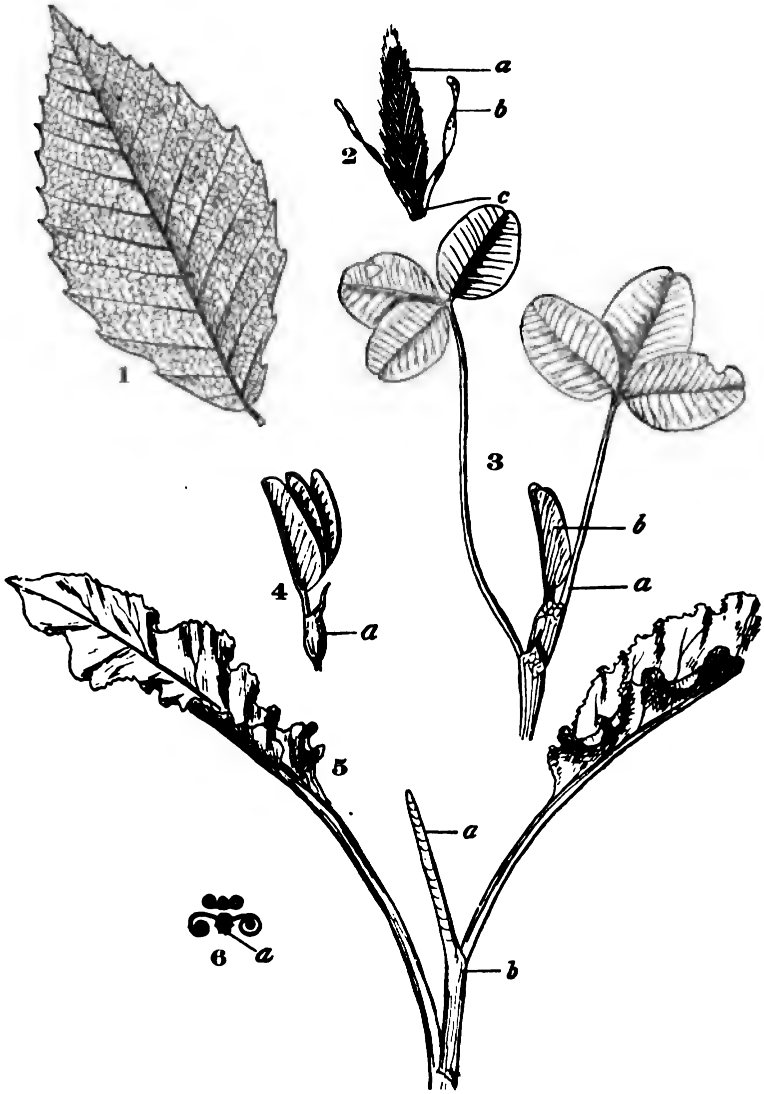


PLATE X., FIG. 1.—Leaf of Fagus ferruginea (1/3 natural size).

FIG. 2.—Young Leaf (about 2/3 natural size), showing, *a*, plicate blade; *b*, one of the thin, scarious stipules: *c*, the petiole.

FIG. 3.—Branch of Trifolium pratense (1/2 natural size), showing two leaves nearly mature, and a young and still folded leaf, *b*, just emerged from between the stipules of the leaf *a*.

FIG. 4.—The Young Leaf in Figure 3 removed, and its leaflets somewhat separated from each other, showing the conduplicate prefoliation. The adnate stipules overlap at their edges, *a*, and enclose a still younger leaf, similarly folded, but much smaller.

FIG. 5.—Branch of Rumex crispus, showing two nearly mature leaves, and a still folded younger one that has partly emerged from its stipular enclosure: *a*, young leaf; *b*, stipular sheath or ochrea of next older leaf.

FIG. 6.—Cross-sections of two very young Leaves of Rumex, somewhat unrolled and separated to show the mode of vernation (magnified about 2 diameters): *a*, dorsal surface of midrib of the older of the two leaves.

EXERCISE X.

TYPES OF LEAF-VENATION.

A SELECTION for study may be made from—(*a*) The leaves of almost any species of Jungermannia, or Moss; as, for example, Jungermannia Schraderi, *Martius;* J. barbata, *Schreb.;* Jubula Hutchinsiæ, *Dumort.;* Funaria hygrometrica, *Sibth.*; Bryum roseum, *Schreb.;* Minium serratum, *Laich.* (*b*) Leaves of the following ferns and gymnosperms: the Common Polypody (Polypodium vulgare, *L.*), the Maidenhair Fern (Adiantum pedatum, *L.*), the Venus-hair Fern (Adiantum capillus-veneris, *L.*), the Shield Fern (Aspidium acrostichoides, *Swartz.*), the Royal Fern (Osmunda regalis, *L.*), and the Ginkho Tree (Salisburia adiantifolia, *Sm.*). (*c*) Leaves of the following monocotyls: the Wandering Jew (Callisia repens, *Willd.*), the Lily of the Valley (Convallaria majalis, *L.*), the Clintonia (Clintonia borealis, *Raf.*), the Bell-wort (Uvularia grandiflora, *Smith*), Solomon's Seal (Polygonatum giganteum, *Dietrich*), the Egyptian Calla (Richardia africana, *Kunth.*), and the Palmetto (Sabal Palmetto, *R. and S.*). (*d*) Leaves of the following dicotyls: the Common Deutzia (Deutzia scabra, *L.*), the Beech (Fagus ferruginea, *Ait.*), the Chestnut (Castanea sativa, *Mill.*, var. Americana), the English Ivy (Hedera helix, *L.*), the Sugar Maple (Acer saccharinum, *Wang.*), the Common Mallow (Malva rotundifolia, *L.*), the Wild Yam (Dioscorea villosa, *L.*), the Common Plantain (Plantago major, *L.*), and the Begonia (Begonia nitida, *Willd.*).

(1) *A Moss Leaf.*—Selecting a leaf from one of the plants mentioned in list *a*, and examining it under a magnifying-glass, it will be found exceedingly simple in structure as compared with that of the Geranium. In no moss or liverwort is to be found any differentiation of the leaf into petiole, blade, and stipules. There may be traced with a magnifying-glass, or in some species even with the naked eye, a very delicate network pervading the leaf, and this at first might be mistaken for the venation; but it

is only the reticulate appearance produced by the walls of the rather large cells composing the leaf. These cells are not of many different kinds, as in the higher plants, but are all nearly alike and mostly arranged in a single layer. There is no differentiation into epidermis and mesophyll, and in many cases not even the beginning of a differentiation into veins. This is true of the leafy-stemmed liverworts generally, and true of many mosses; but some of the latter group possess a very simple venation, usually consisting of a single vein or rib running from base to apex of the leaf, as shown on Plate XII. The cells here are usually more than one-layered, and more elongated than the rest, but are otherwise similar to them. There is no development of fibrous tissues or ducts, such as occur in the veins of the leaves of the higher plants, and the cells contain chlorophyll like the rest.

Here, so to speak, the venation, as well as the whole leaf-structure, is reduced to its simplest terms.

(2) *Forked or Furcate Venation.*—This is illustrated in the great majority of ferns and in some gymnosperms, and is a long step in advance of the venation in mosses. Let it be studied as it is found in the leaf of Osmunda regalis. The leaves are large and bipinnately compound, but it is the venation of the leaflet that one desires to study. The leaflet has all the parts—epidermis, veins, and mesophyll—that were observed in the leaf of the Geranium. In fact, the leaves of ferns approximate very closely in the complexity of their structure those of the highest plants, but the venation is simpler. It will be seen that there is a middle vein, called the *midrib*, running from the base to the apex. Lateral branches pass off from this on either side, and these again branch; and here in their mode of branching is their distinctive characteristic: they *branch by forking*, and not in the ordinary way; that is, the vein separates at its end into two equal parts, one or both of which may again fork in the same way. Moreover, it is to be observed that these branches remain distinct, and do not connect with other branches to form a network. This general plan is called the *furcate* or forked plan of venation, and this particular variety of it is termed the *pinnifurcate*, or pinnately forked, since the branching somewhat resembles that of a feather.

Another variety of furcate venation is illustrated in the leaf

of Salisburia adiantifolia (Pl. XI.). Here the secondary branches of the venation do not come off from a midrib as in Osmunda, but several veins originate in the petiole, and, diverging and repeatedly forking, radiate toward the expanded margin of the leaf. This variety may be distinguished from the other by the term *palmi-furcate.*

In some of the higher ferns—as, for example, Camptosorus, Woodwardia, and Onoclea—some of the branches of the furcations may coalesce with those of adjacent veins, and so form a kind of network, thus forecasting, so to speak, the reticulate mode of venation, which will be studied farther on. This sort of network, however, should not be confounded with that which is so common in the higher plants, and really originates in a different way.

(3) *The Nerved or Parallel Venation.*—Let this be studied first in the Wandering Jew (Callisia repens), a common garden and greenhouse plant, the leaves of which are so transparent that the veins, even the more minute ones, are readily seen. A branch of the plant is shown on Plate XII. The two-ranked, sheathing, ovate-lanceolate leaves are each provided with numerous apparently simple veins which spring from the base and, running somewhat parallel to each other, terminate in the apex. Because the veins appear simple, somewhat like nerves in form, though of course not in function, the type has been called the *nerved* type. A very close inspection under a magnifying-glass will show, however, that the veins are not really simple. There will be discovered minute branches crossing at intervals from one vein to adjacent ones, forming thus a somewhat regular network composed of quadrangular meshes. This is shown on Plate XIII., which represents a part of one of the leaves magnified about two and a half diameters. This reticulum is wholly different from that occurring in a truly reticulate leaf.

Another thing will be observed about this mode of venation if the leaf be closely inspected with a glass—namely, the fact that thicker veins alternate somewhat regularly with thinner and less developed ones.

There are three varieties of this mode of venation. The leaf just studied represents one of them, the *basi-nerved*, appropriately so called because the veins originate at the base of the leaf and run to the apex.

Another variety of nerved venation is observed in a few plants, especially in some palms. Here the veins, originating at the base, do not terminate in a narrow apex, but diverge in a radial or palmate manner to an expanded margin. Hence this mode of venation has been called the *palmi-nerved.*

The third variety is the *pinni-nerved,* illustrated in the leaf of the Calla and in that of the Banana. Here the veins do not all originate in the base of the blade, but run from a midrib to, or nearly to, the margin. The lateral veins have substantially the same character and arrangement as those of basal origin in the other leaves just described. In some plants having this type of venation, besides the minute cross-veinlets, the main nerves send out larger branches at their ends, which unite with similar ones from adjacent nerves to form a continuous, usually wavy, submarginal vein running from the base to the apex of the leaf. This is the case with the leaflets of the Indian Turnip (Arisæma triphyllum).

The nerved mode of leaf-venation is by far the most common among monocotyls, the chief exceptions occurring in the Arum and Yam families, where the leaves are mostly reticulate. Most gymnosperms also have nerved leaves.

(4) *The Reticulate or Netted Mode of Venation.*—This, in one of its varieties, may be studied in the leaf of Deutzia scabra, *L.* Here it will be observed that the larger veins break up by repeated lateral branching into finer and finer divisions, and that these anastomose with adjacent branchlets, forming a complicated and more or less irregular network, very different in its character from such a network as has been seen in a nerved leaf, and also very different from that which occurs in some ferns. The venation of a part of Deutzia leaf, magnified four diameters, is shown on Plate XIII.

It often, though not always, happens in this type of venation that the free end of a veinlet terminates in the interior of a mesh, as in the example now being studied, or as is even more beautifully shown in the leaf of Cobæa scandens, illustrated on page 196 of the *College Botany.*

It frequently happens also that a marginal sub-vein is formed by the coalescence of veinlets near the edge of the leaf.

Manifestly, this mode of venation is the most effective, both as

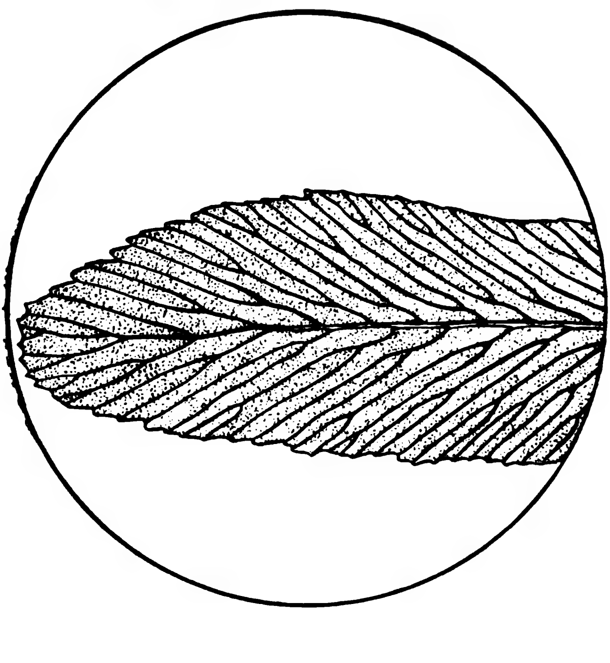
a support and as a means of distributing nutriment to the mesophyll cells, and it is found, as would naturally be expected, the prevalent mode of venation in the highest group of plants, the dicotyls.

(*a*) The *pinni-reticulate*, or pinnately-netted, venation is the particular variety represented in the leaf of Deutzia. It has a main rib or *midrib* running from base to apex, from which issue laterally the *ribs;* these in turn send off *veins*, and these branch into *veinlets.* It is the possession of a midrib which specially distinguishes this variety from the others of the type.

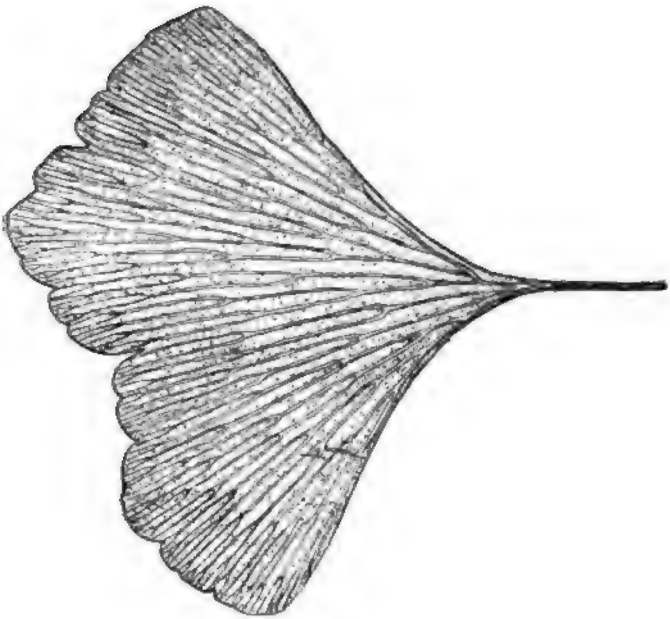
(*b*) *The Palmi-reticulate Leaf.*—This is well illustrated in the Common Ivy (Hedera helix, Pl. XII.), and is distinguished from the preceding by the fact that there are several large veins springing from the top of the petiole and diverging to the margin. These branch repeatedly to form a network similar to that already described. Since the main veins are arranged in a radiating manner, this variety is also called the *radiately-reticulate* leaf.

(*c*) *The Costate-reticulate or Rib-netted Leaf.*—This variety is rarer than the other forms, but is occasionally met with. The Cinnamon and Wild Yam afford illustrations. The peculiarity of this form of venation consists in the fact that two or more large veins spring from the top of the petiole, and, after diverging somewhat, come together again at the apex of the blade, the spaces between being filled with a network similar to that in other reticulate forms.

The reticulate type is pre-eminently that found among dicotyls. Only in very rare instances are the foliage leaves of the members of this group nerved or parallel veined. Netted veined leaves, however, differ from each other very considerably in the closeness of the network. In many cases the meshes are very intricate and fine; in others the network is much less complex and relatively coarse, showing even a close approach to the nerved or parallel forms, and so in leaf-structure the two great groups sometimes overlap.



1



2

PLATE XI., FIG. 1.—Part of Leaflet of Osmunda regalis, showing pinni-furcate venation (magnified about 4 diameters).

FIG. 2.—Leaf of Salisburia adiantifolia, showing palmi-furcate venation (2/3 natural size).

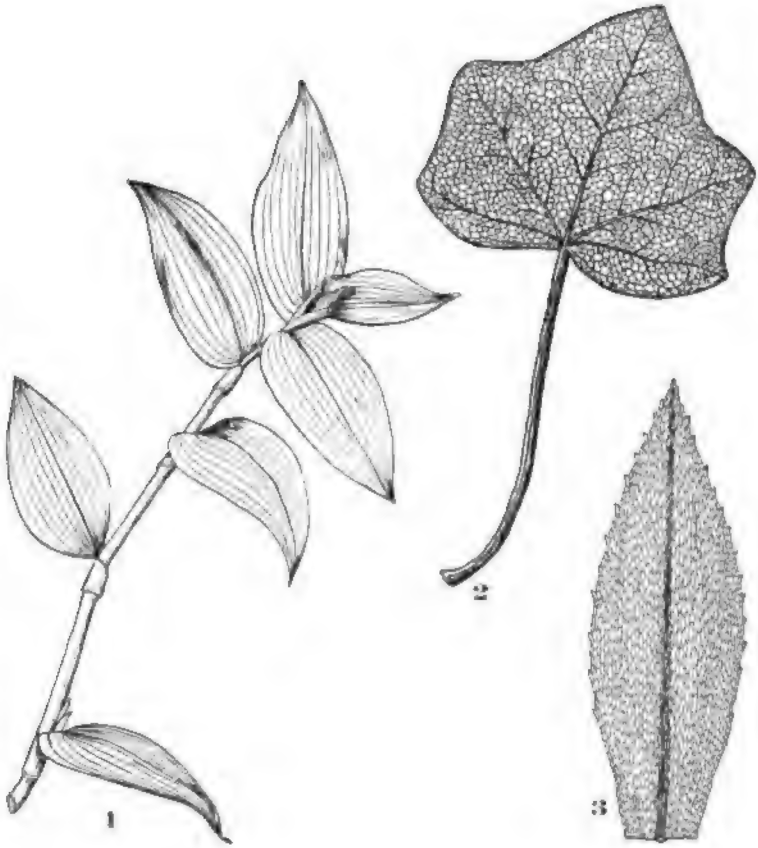
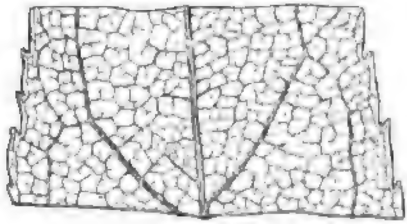


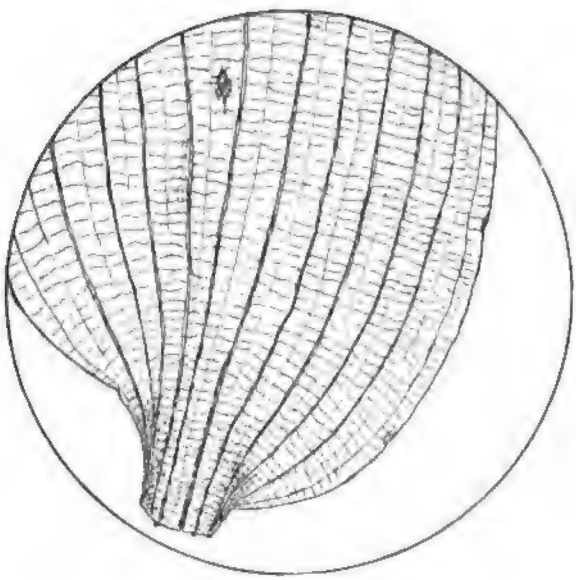
PLATE XII., FIG. 1.—Branch of Callisia repens, showing sheathing, two-ranked leaves which are basi-nerved in their venation ($\frac{2}{3}$ natural size).

FIG. 2.—Leaf of Hedera helix, showing palmi-reticulate venation ($\frac{2}{3}$ natural size).

FIG. 3.—Leaf of Moss (magnified about 15 diameters), showing that, with the exception of the midrib, it is composed of a one-layered sheet of similar cells.



1



2

PLATE XIII., FIG. 1.—Part of Leaf of Deutzia scabra, showing pinni-reticulate venation (magnified about 6 diameters).

FIG. 2.—Portion of Leaf of Callisia repens (enlarged about 4 diameters), showing nerves and cross-veinlets.

EXERCISE XI.

THE BRANCHING OF LEAVES.

THE leaves of the following plants may be studied and compared: the Basswood (Tilia Americana, *L.*), the Dandelion (Taraxacum officinale, *Weber*), the White Oak (Quercus alba, *L.*), the Shepherd's Purse (Capsella bursa-pastoris, *Moench*), the Celandine (Chelidonium majus, *L.*), the Rue (Ruta graveolens, *L.*), the Smooth Rose (Rosa blanda, *Ait.*), the Silver Weed (Potentilla anserina, *L.*), the Trumpet Creeper (Tecoma radicans, *Juss.*), Common Polypody (Polypodium vulgare, *L.*), the American Mountain Ash (Pyrus Americana, *DC.*), the Agrimony (Agrimonia parviflora, *Ait.*), the Silver Maple (Acer dasycarpum, *Ehrh.*), the Cranesbill (Geranium maculatum, *L.*), the Castor Bean (Ricinus communis, *L.*), the Summer Grape (Vitis æstivalis, *Michx.*), the Strawberry (Fragaria Virginiana, *Mill.*), the Cinquefoil (Potentilla Canadensis, *L.*), and the Meadow Rue (Thalictrum dioicum, *L.*).

In comparing different leaves it will be found that some have blades composed of a single piece, and that this is entire or plain-margined; in others the blade is more or less wavy, scalloped, or toothed in various ways; in still others the indentation becomes so deep as evidently to forecast those forms in which the blade is separated into several distinct pieces, as in the Clover leaf already studied, the more deeply indented forms being variously described, according to the character or depth of the indentations, as incised, cleft, parted, or divided; and, lastly, there are the truly compound forms, where, as in the Locust and Rose, the blade is separated into two or more distinct pieces.

Between the blade that is barely toothed on its margin and the one that is compound there is every possible gradation. Even on the same plant there may sometimes be found leaves that are entire or nearly so, and others that are very much divided or even compound. In the Cruciferæ or Cress family numerous examples

of this kind are met with, and in many aquatics the floating leaves or those borne above the water are either entire or but slightly segmented, while the submerged leaves of the same plant are separated into exceedingly numerous and very fine divisions.

In the division or compounding of the leaf-blades the plan always follows that of the venation: if the leaf is pinnately veined, the leaflets or segments will be pinnately arranged; and if the venation is palmate or radiate, the leaflets or segments will be palmately arranged.

The leaves of dicotyls and ferns show a much stronger tendency toward branching forms than do those of monocotyls and gymnosperms.

Let the following leaves be studied by way of illustration:

(1) *Leaf of Dandelion.*—The blade is oblanceolate, acute, tapering into a short petiole, membranous and herbaceous in texture, somewhat pubescent on its two surfaces and strongly so on the prominent midrib below, and its venation is pinni-reticulate. It is clearly a simple leaf, but shows a plain tendency to the division or branching of its blade. Its marginal incisions are much more irregular than are those of most leaves, the teeth varying in size, in inclination, and in distance apart. The sharp, somewhat hooked, and irregular character of the teeth bears some resemblance to the teeth of a lion or other carnivorous animal, and this fact explains the origin of several of the names the plant has borne—Leontodon, Dens-leonis, and the common name Dandelion. Such a word as *incised* does not fully describe a margin like this, since many of the teeth incline backward or are hooked in that direction; hence, owing to the desirability of making descriptive terms as brief and precise as possible, the term *runcinate* has been applied to it. The leaf is shown, one-half natural size, on Plate XIV. (Fig. 1).

(2) *Leaf of the Trumpet Creeper.*—Here the leaf also consists of blade and petiole, the stipules, as in Dandelion, being absent; but the blade is obviously separated into seven distinct bladelets, and is therefore compound. One must not conclude, though, that every leaf which is separated into segments to the midrib is to be regarded as compound. If the segment is not contracted at its base, or if somewhat contracted, but not so much so as to prevent the green pulp of the segment from joining the midrib or rachis,

it is still regarded as simple and is called a *divided* leaf. But if the leaflets are distinctly stalked, or if, whether stalked or sessile, they are connected with the rachis by a joint, or even if, possessing neither stalk nor joint, they are so strongly contracted at the base as to separate the leaf-pulp from the rachis, the leaf is regarded as compound.

In the compound leaf the part corresponding to the midrib of the simple leaf, if present, is called the *rachis;* the stalks of the leaflets which join them to the rachis are called the *petiolules;* and one of the leaflets is called a *foliole* or foliolum.

In the leaf of the Trumpet Creeper, shown on Plate XIV. (Fig. 2), *a* is the petiole, *b* is the rachis, *c* is the petiolule of the terminal foliole. The leaf is *pinnately compound,* since its leaflets are arranged along a lengthened rachis; but, this leaf having an odd terminal leaflet, it is important to distinguish it from a pinnate leaf having an even number of leaflets, so it is called an *imparipinnate* leaf. The leaflets may be described as would be the blades of a simple leaf. In this instance they are ovate in general outline, obtuse at the base, acute or acuminate at the apex, and coarsely serrate on the margin. The venation is pinni-reticulate, the texture membranous and herbaceous, and the surface glabrous.

It should be observed that the leaves of this species commonly possess either nine or eleven leaflets.

(3) *The Leaf of the Silver Maple.*—Here, as in the Dandelion, may be found the simple leaf tending to a compound form, but, the venation being palmate instead of pinnate, and there being five main veins radiating from the top of the petiole, the blade is parted into five radiating main divisions or lobes. Since the principal incisions extend from an imaginary general outline rather more than halfway to the top of the petiole, the blade may be described as *palmately five-cleft.* To this description of the margin, however, to render it complete, must be added the statement that the segments are *incised* and *serrately toothed.* The leaf is also petiolate, exstipulate, cordate, membranous and herbaceous, glabrous on the ventral surface, and both pubescent and glaucous on the dorsal surface. The leaf is shown, one-half natural size, on Plate XIV. (Fig. 3).

(4) *The Leaf of the Lupine.*—This leaf is complete, having lamina, petiole, and stipules. The stipules are adnate at the base

and free above. They are linear and entire. The petiole is elongated and somewhat channelled on the upper surface toward its base, and from its apex radiate the numerous leaflets, which vary in number from seven to eleven or more. These are sessile, jointed to the petiole, pinnately reticulate, oblanceolate in outline, mucronate at the apex, entire-margined, membranous-herbaceous in texture, and pubescent above and below—as, in fact, are also the other parts of the leaf.

Such a leaf as that illustrated on Plate XIV. (Fig. 4) might be briefly described as a *palmately octo-foliolate leaf*, or, still more briefly, as an *octonate* leaf.

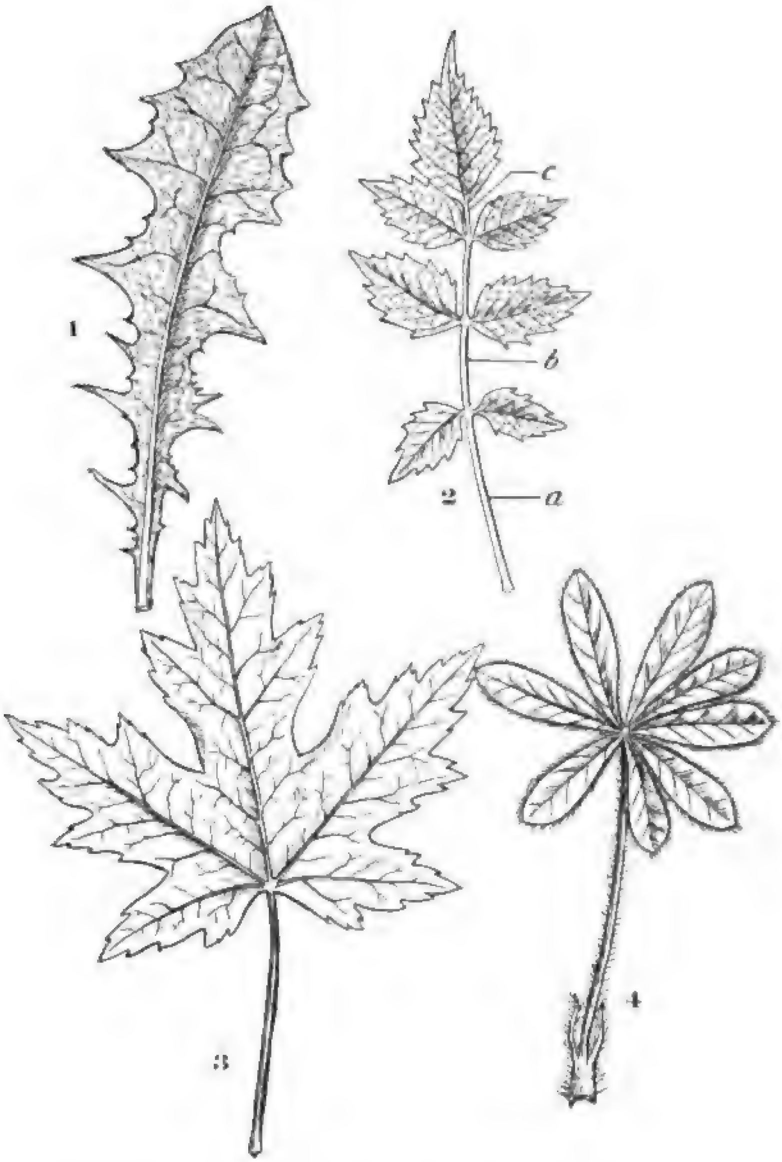


PLATE XIV., FIG. 1.—The Runcinate Leaf of the Common Dandelion.

FIG. 2.—The Impari-pinnate Leaf of the Trumpet Creeper: *a*, petiole of leaf; *b*, rachis; *c*, petiolule of terminal leaflet.

FIG. 3.—Palmately-cleft Leaf of the Silver Maple.

FIG. 4.—The Octonate Leaf of the Common Lupine. (All of the figures ½ natural size.)

EXERCISE XII.

STUDY OF SOME SPECIALLY-MODIFIED LEAVES.

SELECTIONS may be made from the following plants: the Locust (Robinia Pseudacacia, *L.*), the Common Greenbrier (Smilax rotundifolia, *L.*), the Beach Pea (Lathyrus maritimus, *Bigelow*), the Yellow Vetchling (Lathyrus Aphaca, *L.*), the Prickly Pear (Opuntia Rafinesquii, *Englm.*), the Butterwort (Pinguicula vulgaris, *L.*), the Bladderwort (Utricularia vulgaris, *L.*), the Round-leaved Sundew (Drosera rotundifolia, *L.*) or the Long-leaved Sundew (Drosera intermedia, *Hayne.*, var. Americana, *DC.*), Venus's Fly-trap (Dionæa muscipula, *Ellis*), the Pitcher-plant (Sarracenia purpurea, *L.*), the Trumpet-plant (Sarracenia flava, *L.*), and the East Indian Pitcher-plant (Nepenthes ampullaria, *Jack.*).

Observation has already been made of leaves under their ordinary forms—namely, as foliage, and also variously disguised as bud-scales, as bulb-scales both fleshy and membranous, as rhizome-scales, and as tuber-scales. But there are various other disguises or modifications which they assume, fitting them for as various uses. In fact, no organ of the plant presents itself under such a variety of forms or serves such a variety of uses. Leaves are sometimes wholly or partly modified into spines for defence, into tendrils for climbing, into pitchers and traps for catching insects, and into the various organs of the flower—sepals, petals, stamens, and pistils to subserve the functions of reproduction.

For this study a selection is made of two leaves which serve to entrap insects—those of Sarracenia purpurea and those of Drosera rotundifolia.

(1) *The Pitcher-plant* is not uncommon in our northern bogs. Its pitcher-shaped leaves are all radical, and form a tuft or rosette with their apices pointing upward. From the centre of the mass of leaves rises the usually solitary scape to the height of about a foot; this scape bears the conspicuous, nodding, pentamerous, pur-

ple flowers, which are remarkable for the large, shield-shaped, five-pointed, persistent stigmas.

Each leaf consists of an upper part (Pl. XV. Fig. 1, *a*), called the *lip*; a hollow portion (*b*) which is usually filled, or partly so, with water, and which may be called the *bowl*; a flattened expansion (*c*) on the ventral surface, called the *wing*; and a short *stalk* (*d*). The venation, it will be observed, is costate-reticulate; the exterior of the pitcher is smooth, more or less purple-blotched, and slightly glandular along the wing. The interior is partly hairy and partly very smooth, and the water may usually be observed to contain the remains of numerous insects in various stages of decomposition.

It is not easy to trace the structural relations between this and an ordinary leaf, but there are reasons, derived from analogy and from the study of the very young leaves, for believing that the lip represents the lamina, and the rest, including the wing, bowl, and stalk, represents the petiole. The petiole is thus analogous to the vertically flattened ones, called phyllodia, of the Australian acacias, differing from them chiefly in the fact that a part of it has become hollow. In the very young leaf, however, the hollow does not exist, and the analogy is then closer still.

The stipules are not present, unless the lateral widening at the base of the petiole may be regarded as due to stipules which have become adnate.

The water found in the bowl may partly be caught from rains; but it cannot be wholly so, for it is present, though in diminished quantity, even in dry weather and in pitchers which have not yet opened. Moreover, in some other Sarracenias, and in Darlingtonia, a California relation of the genus, the orifice is protected from the entrance of rain, and yet water in considerable quantity is usually present in the bowl. The water is therefore partly a secretion of the plant. Besides the fact that in this water, when the leaf is mature, are usually to be found in great numbers insects drowned and in various stages of putrefaction, there is much other evidence to show that the leaf is adapted to the function of insect-trapping, the plant making use of the captured creatures for food. This is shown not only by the structure, but by direct observation of the process of capture, which may readily be seen where the plants are abundant.

It will be noted that the lip on its upper or ventral surface is provided with numerous stiff, sharp, and downwardly-pointing hairs, which do not much interfere with the progress of an insect toward the interior of the bowl, but present a decided obstacle to its progress in the opposite direction. These hairs disappear at or near the throat of the pitcher, and the interior becomes exceedingly smooth, forming a surface on which the footing of even a fly or an ant is very insecure. The throat is also somewhat contracted, making it difficult for an insect, when once inside, to fly outward. The smooth area extends downward half or two-thirds the length of the bowl, and is then succeeded by an area covered with longer and more slender downwardly-pointing hairs. These serve to entangle insects that fall into the water, and so hasten their drowning.

But the trap is also baited. Along the wing and about the throat on the inside of the pitcher there exudes a sweet secretion which entices insects to the slippery interior surface, and thus renders their destruction nearly certain. It was at one time supposed that this secretion had an intoxicating effect, but this has not been proven.

Whether or not the other secretion at the bottom of the bowl contains any specially digestive principle has not yet been determined with certainty, though probably it does not. But the decaying bodies of the insects doubtless form a nutritious mixture which is to some extent absorbed by the leaves and nourishes the plant.

Experiment seems to show that the water, even when first secreted, possesses greater asphyxiating power upon insects than does rain-water, probably by reason of its more readily wetting their spiracles. What the constituents are that give it this property is not known.

The Pitcher-plant is therefore certainly insectivorous, and most insects that frequent marshy places are liable to be captured by it. But there are at least two curious exceptions—a species of moth and a species of fly. These insects are exceptional among their kind in having in their feet hooks sufficiently long and sharp to enable them to cling securely to the smooth interior walls. Both species deposit their eggs in the putrid contents of the pitcher, and the larvæ feed and fatten upon the putrescent matters until

ready to assume the winged condition. The larva of the fly even attacks the wall of the pitcher itself, bores holes through it, and destroys it. So, insect-devourer that it is, like most other plants, it has its insect enemies, which obtain their living at its expense.

(2) *The Round-leaved Sundew* also grows in marshy places, and is to be found in suitable situations over the whole northern hemisphere. Its round, petiolate leaves, half a dozen or more in number, are all radical and lie flat upon the ground. From the centre of the circle there rises, to the height of from three to five inches, the single, slender, erect flower-stalk, which bears a more or less one-sided raceme of inconspicuous white flowers.

The blades of the leaves, about half an inch broad, are thickly studded on the margin and upper surface with hairs or tentacles each of which is tipped with a glistening gland which resembles a minute drop of dew. The tentacles are structurally much more complex and better developed than are ordinary hairs, to accord with their more complex functions.

This leaf is also an insect-trap, and a very perfect one at that; but how different in its construction from that of the Pitcher-plant! The prey consists of small flies, ants, etc., that are attracted to it apparently by the glittering, dew-like drops on the ends of the tentacles. These, when ready to make their capture, are spread out as shown on Plate XV. (Figs. 3 and 4, which are upper-surface and edge views, respectively, of one of the leaves). An insect alighting upon the leaf is nearly certain to get its legs entangled in the very adhesive droplets at the ends of the tentacles, and usually its frantic struggles for freedom only serve to bind it more securely by bringing its body into contact with more of the glands. But the tentacles are far from being merely mechanical in their action: they are endowed with an exquisite sensitiveness and with the power of movement in response to stimulus. Even a minute food-particle placed on the end of one of the exterior tentacles causes it to bend slowly but surely over toward the centre of the leaf. Not only this, but the stimulus is transmitted to adjacent tentacles, which also bend in the same direction, and if the object be of considerable size—say as large as a gnat—all the tentacles may become involved in these movements. The insect is thus carried to the centre of the leaf, and the leaf itself finally rolls inward to some extent, so that the unfortunate

creature becomes nearly or wholly enveloped, and of course asphyxiated.

Charles Darwin, who gave this plant a most careful study, experimented on the sensitiveness of the tentacles, and found that a bit of human hair weighing only $\frac{1}{78740}$ of a grain, placed upon a gland, was sufficient to cause the tentacles to sweep through an angle of 180°; and, even more remarkable than this, he found that less than a millionth of a grain of phosphate of ammonia in solution sufficed to produce similar movements.

Not less strange and wonderful is the digestive process which supervenes. The insect being secured at the centre of the leaf, the secretion of the tentacles now changes its character, becoming less viscid than before, acid in its reaction, and containing some digestive principle analogous to, if not identical with, pepsin. This secretion is poured out copiously over the victim's body, and digestion goes on until there is nothing left of it but the insoluble skeleton. After this the leaf gradually unrolls, the tentacles straighten out, the glands again secrete the viscid droplets, and all is in readiness for another capture.

It has been further proven beyond peradventure that the dissolved or peptonized albuminous materials are absorbed into the interior of the leaf and appropriated by its cells. The plant, in fact, digests and assimilates in truly animal fashion. While, however, it profits by an animal diet, it is not wholly dependent on one, for the leaves still contain abundance of chlorophyll, which, as in other plants, enables it to assimilate carbon dioxide from the atmosphere.

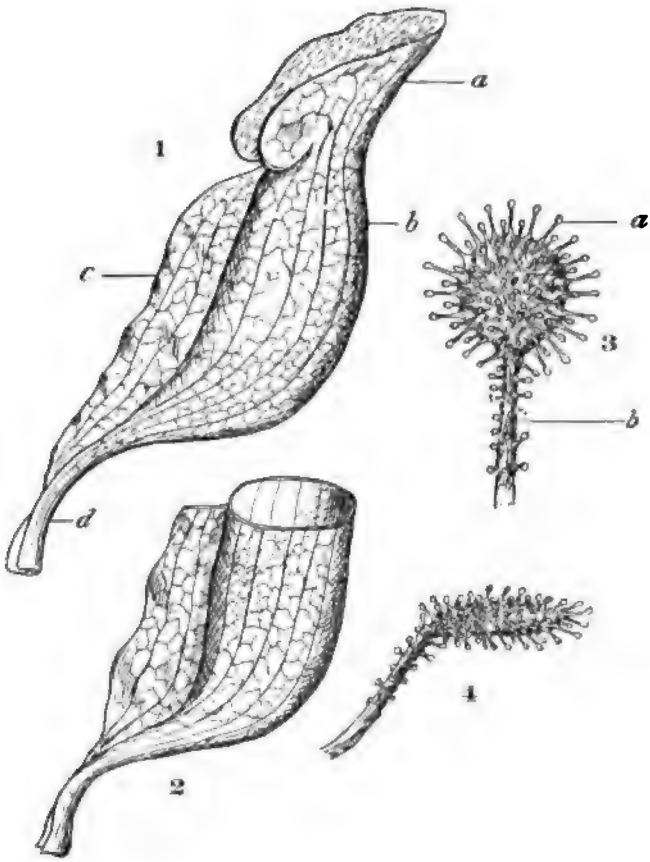


PLATE XV., FIG. 1.—Leaf of Sarracenia purpurea (⅔ natural size): *a*, lip; *b*, bowl; *c*, wing; *d*, stalk, or lower part of petiole.

FIG. 2.—The same Leaf cut through transversely, showing interior cavity.

FIG. 3.—Leaf of Drosera rotundifolia (natural size): *a*, one of the tentacles; *b*, petiole. The figure shows the upper surface, the lower surface not being provided with tentacles.

FIG. 4.—Edge view of Leaf of Drosera.

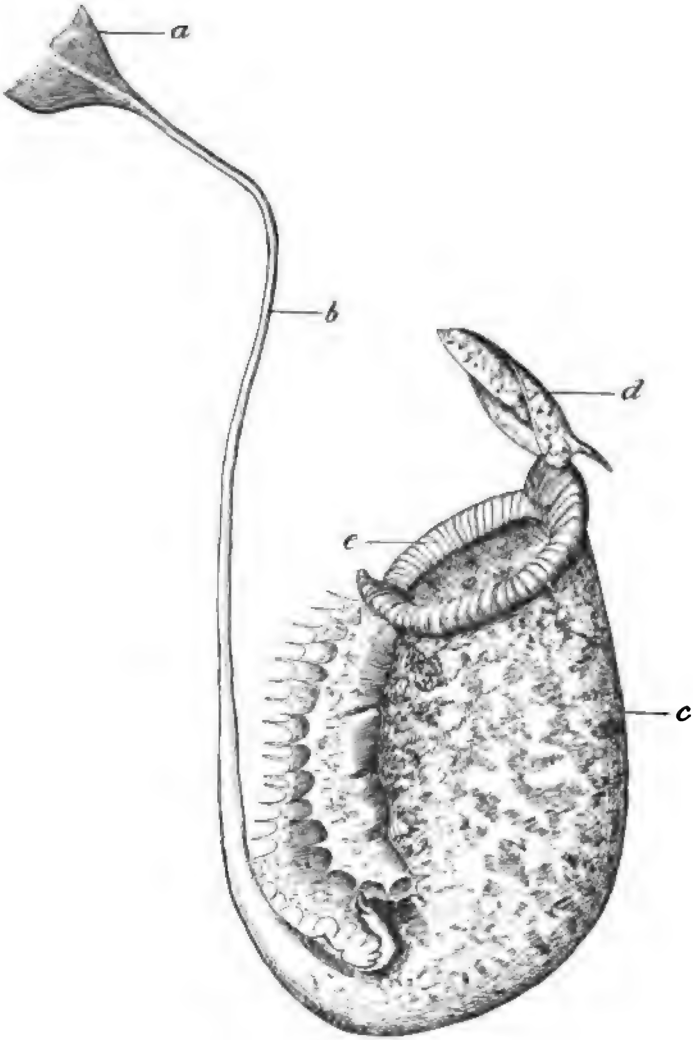


PLATE XVI.—Pitcher-like Insect-trap of one of the East Indian Pitcher-plants, Nepenthes Chelsoni (½ natural size). The lower part, a small portion of which is seen at *a*, is flat, like an ordinary leaf-blade, and serves the same purpose. The middle portion is developed into a tendril, *b*, which serves the purpose of climbing, and at the end of this tendril is developed the pitcher, *c*, which serves as an insect-trap. This is surmounted by a lid, *d*, which serves to keep out much useless extraneous matter and any excess of water from rains, while permitting the access of insects. The latter are attracted by sweet secretions on the lid and about the mouth of the pitcher on the inside. At the throat is a strong fold, *e*, bordered with downwardly-pointing spines to prevent the escape of the prey. The inner surface is provided with numerous glands which secrete the fluid that serves at once to drown the insects and to digest their bodies.

FORM FOR THE STUDY OF LEAVES.

I. **Kind.**
  1. Foliage leaf.
  2. Ascidium.
  3. Insect-trap.
  4. Spine.
  5. Tendril.
  6. Scale.
  7. Phyllodium.

II. **Prefoliation.**
  1. Reclinate.
  2. Conduplicate.
  3. Convolute.
  4. Circinate.
  5. Involute.
  6. Revolute.
  7. Equitant.
  8. Obvolute.
  9. Triquetrous.

III. **Phyllotaxy.**
  1. *Whorled.*
    a. Opposite.
    b. Decussate.
    c. In threes.
    d. In fours.
    e. In fives.
    f. Leaves numerous in each whorl.
  2. *Alternate.*
    a. Distichous, or two-ranked.
    b. Tristichous, or three-ranked.
    c. Pentastichous, or five-ranked.
    d. Octastichous, or eight-ranked.
    e. Triskaidekastichous, or thirteen-ranked.
    f. Twenty-one ranked.

IV. **Duration.**
  1. Persistent.
  2. Deciduous.
  3. Fugacious.

V. **Position.**
  1. Cauline.
  2. Rameal.
  3. Radical.

VI. **Parts Present.**
  1. Lamina.
  2. Petiole.
  3. Stipules.

VII. **Lamina.**
  1. *Simple.*
    (1) Terete.
    (2) Awl-shaped.
    (3) Filiform.
    (4) Flattened.
      a. General outline.
        Orbicular.
        Linear.
        Oblong.
        Elliptical.
        Ovate.
        Obovate.
        Lanceolate.
        Oblanceolate.
        Hastate.
        Auriculate.
        Sagittate.
        Cordate.
        Obcordate.
        Panduriform.
        Flabelliform.
        Peltate.
        Reniform.
        Length.
      b. Base.
        Acute or cuneate.
        Acuminate.
        Obtuse or rounded.
        Truncate.
        Retuse.
        Cordate.
        Reniform.
        Auriculate.
        Hastate.
        Sagittate.
        Oblique.
      c. Apex.
        Acute.
        Acuminate.
        Obtuse.
        Retuse.
        Emarginate.
        Obcordate.
        Mucronate.
        Cuspidate.
        Aristate.
      d. Margin (indentations shallow or none).
        Entire.
        Serrate.
        Serrulate.
        Biserrate.
        Dentate.
        Denticulate.
        Bidentate.
        Crenate.
        Crenulate.
        Bicrenate.
        Repand.
        Undulate.
        Sinuate.
        Spinose.
        Crispate.
      e. Margin (indentations deep).
        a. Palmate forms.
          Incised.
          Lobate:
            Bilobate.
            Trilobate.
            Quadrilobate.
            Quinquelobate.
            Sexilobate.
            Septilobate.
          Cleft:
            Bifid.
            Trifid.
            Quadrifid.
            Quinquefid.
            Sexifid.
            Septifid.
            Multifid.
          Parted:
            Bipartite.
            Tripartite.
            Quadripartite.
            Quinquepartite.
            Sexipartite.
            Septipartite.
            Multipartite.
            Pedate.
          Divided:
            Bisect.
            Trisect.
            Quadrisect.
            Quinquesect.
            Sexisect.
            Septisect.
            Multisect.
        b. Pinnate forms.
          Incised.
          Runcinate.
          Lobate:
            Trilobate.
            Quadrilobate.
            Quinquelobate.
            Sexilobate.
            Septilobate.
            Multilobate.
            Lyrately-lobed.
          Cleft:
            Trifid.
            Quadrifid.
            Quinquefid.
            Sexifid.
            Septifid.
            Multifid.
            Lyrately-cleft.
          Parted:
            Tripartite.
            Quadripartite.
            Quinquepartite.
            Sexipartite.
            Septipartite.
            Multipartite.
            Lyrately-parted.
            Pectinate.
          Divided:
            Trisect.
            Quadrisect.
            Quinquesect.
            Sexisect.
            Septisect.
            Multisect.
            Lyrately-divided.
            Bi-pinnatisect.
            Pinnately-dissected.
  2. *Compound.*
    (1) Palmate forms.
      a. Binate or bifoliolate.
      b. Ternate.
      c. Biternate.
      d. Triternate.
      e. Quadriternate.
      f. Ternately-decompound.
      g. Quadrate.
      h. Quinate.
      i. Sextate.
      j. Septinate.
      k. Octate.
      l. Palmately multifoliolate.
    (2) Pinnate forms.
      a. Paripinnate (number of leaflets).
      b. Imparipinnate (number of leaflets).
      c. Cirrhosely-pinnate (number of leaflets).
      d. Interruptedly-pinnate (number of leaflets).
      e. Lyrate (number of leaflets).
      f. Bipinnate.
      g. Tripinnate.
      h. Quadripinnate.
      i. Pinnately-decompound.

FORM FOR THE STUDY OF LEAVES (CONTINUED).

(3) Shape of leaflet.
  a. General outline.
    Filiform.
    Orbicular.
    Linear.
    Oblong.
    Elliptical.
    Ovate.
    Obovate.
    Lanceolate.
    Cordate.
    Obcordate.
    Length.
  b. Base.
    Acute or cuneate.
    Obtuse or rounded.
    Cordate.
    Oblique.
  c. Apex.
    Acute.
    Acuminate.
    Obtuse.
    Retuse.
    Obcordate.
    Mucronate.
    Cuspidate.
    Aristate.
  d. Margin.
    Entire.
    Serrate.
    Serrulate.
    Biserrate.
    Dentate.
    Denticulate.
    Bidentate.
    Crenate.
    Crenulate.
    Bicrenate.
    Repand.
    Undulate.
    Sinuate.
    Spinose.
    Crispate.
    Incised.
    Lobate.
    Cleft.
    Parted.
    Divided.

3. *Venation.*
  (1) Furcate.
    a. Palmi-furcate.
    b. Pinni-furcate.
  (2) Nerved.
    a. Basi-nerved.
    b. Palmi-nerved.
    c. Pinni-nerved.
  (3) Reticulate.
    a. Palmi-reticulate.
    b. Pinni-reticulate.
    c. Costate-reticulate.

4. *Texture.*
  (1) Herbaceous.
  (2) Scarious.
  (3) Membranous.
  (4) Succulent.
  (5) Coriaceous.

5. *Surface.*
  (1) Glabrous.
  (2) Glaucous.
  (3) Punctate.
  (4) Glandular.
  (5) Rugose.
  (6) Scabrous.
  (7) Verrucose.
  (8) Pubescent.
  (9) Puberulent.
  (10) Sericeous.
  (11) Lanuginous.
  (12) Tomentose.
  (13) Villose.
  (14) Pilose.
  (15) Floccose.
  (16) Hispid.
  (17) Strigose.
  (18) Spinose.
  (19) Echinate.
  (20) Aculeate.

6. *Insertion.*
  (1) Sessile.
  (2) Clasping.
  (3) Sheathing.
  (4) Perfoliate.
  (5) Connate.
  (6) Decurrent.

VIII. PETIOLE.

1. Length as compared with lamina.
2. Flattened on ventral surface.
3. Channelled on ventral side.
4. Flattened vertically.
5. Wing-margined.
6. Phyllodium.

IX. STIPULES.

1. Foliaceous.
2. Scarious.
3. Caducous.
4. Adnate.
5. Half-sagittate.
6. Ochreate.
7. Forming spines.
8. Forming tendrils.
9. Forming glands.

X. TASTE.

1. Insipid
2. Bland.
3. Sweet.
4. Bitter.
5. Mucilaginous.
6. Pungent.
7. Acrid.
8. Warm.
9. Burning.
10. Cooling.
11. Astringent.
12. Nauseous.
13. Prickling.
14. Saline.
15. Alkaline.
16. Acidulous.

XI. ODOR.

1. Odorless.
2. Faint.
3. Agreeable.
4. Aromatic.
5. Mint-like.
6. Balsamic.
7. Camphoraceous.
8. Terebinthinous.
9. Pungent.
10. Musky.
11. Disagreeable.
12. Irritating.
13. Nauseous.
14. Narcotic.
15. Putrid.
16. Fetid.

EXERCISE XIII.

A TYPICAL FLOWER OF A DICOTYL.

In beginning the study of flowers it is well to have in mind a type or pattern flower with which all others may be compared. This is not merely a great convenience, but it is probable that all or nearly all of the flowers of the two higher groups of flowering plants, the monocotyls and the dicotyls, no matter how irregular, defective, or unsymmetrical they may now be, have been modified from one or a few simple structural types. The study and comparison of a large number of flowers have enabled botanists to determine with a good deal of certainty what these types are for monocotyls and dicotyls respectively.

Most existing flowers have in the course of time been considerably, sometimes profoundly, modified from the type, and these modifications exist in great variety among different species; but there are still a few which conform rather closely to the original plan. From some of these the selections for study will be made.

The plan will be, first, to take up a nearly typical flower from the dicotyls, and after its structure has been comprehended to study some others that show more or less considerable deviations from the type; then, finally, to proceed in a similar manner to the study of monocotyls.

The following dicotyls produce flowers that approach quite closely to the typical form: the Mossy Stonecrop (Sedum acre, *L.*), the Purple Stonecrop (Sedum pulchellum, *Michx.*), the Live-for-ever (Sedum Telephium, *L.*), the Common Flax (Linum usitatissimum, *L.*), the Perennial Flax (Linum perenne, *L.*), the Wild Cranesbill (Geranium maculatum, *L.*), the Common Wood-sorrel (Oxalis Acetosella, *L.*), the Yellow Wood-sorrel (Oxalis corniculata, *L.*).

The flower of the Common Flax shall serve the present purpose.

The plant is a rather slender, erect, somewhat branching, and

smooth annual herb which grows to the height of from thirty to sixty centimetres. Its bast-fibres constitute one of our most valuable textile materials—linen—and its seeds are the source of the very useful linseed oil. The leaves are alternate, sessile, linear-lanceolate, entire, and from two to four centimetres in length. The corymbosely arranged branches are terminated by one-sided false racemes of blue flowers, which are the special object of this study.

(1) *The Floral Symmetry.*—Observing one of the flowers closely, it will be found to possess four different kinds of floral organs, each organ representing a leaf, though quite different from ordinary leaves in form, and the different kinds being arranged in successive circles or whorls. The outer whorl, called the *calyx*, is composed of green leaves, each termed a *sepal;* the second, called the *corolla*, is composed of blue and much larger pieces, each termed a *petal;* the third whorl, called the *andrœcium*, consists of individual pieces called *stamens* which are very different from the other organs in size and appearance. Their function is to produce the fertilizing dust called *pollen*. The organs heretofore mentioned are separate from each other, each arising independently of the others from the receptacle, but the stalks or filaments of the stamens are united at their bases, forming a short tube. It will moreover be observed in many flowers of this species that between the bases of each pair of filaments is a small thread-like body. There are the same number of these as of stamens—namely, five—and they are doubtless to be regarded as stamens, a fast disappearing remnant of a second whorl of these organs. They are technically called *staminodes*.

Interior to the andrœcium is the innermost floral whorl, constituting the *gynœcium*. It is, at the base at least, a single organ, though its whole structure shows that it is really made up of five leaf-elements, or *carpels*. The upper parts, in fact, *styles* and *stigmas*, are still distinct, and the lower part, or *ovary*, shows by the fact that it is five-lined exteriorly and five-celled interiorly that it is a composite body made up of five pieces.

It will be observed that the successive whorls alternate with each other. For example, the petals are not inserted on the receptacle directly in front of the sepals, but in front of the interspaces between them. The relative arrangement is shown on the

ground plan on Plate XVII. (Fig. 4). Another noteworthy fact is the resemblance between the pieces of each whorl. These pieces are alike in size, shape, and coloring—a fact expressed by saying that they are *regular*.

Inferences can now easily be drawn as to the type or model on which the flower was originally constructed: (1) It was five-whorled; (2) It was symmetrical; that is to say, the whorls alternated with each other; (3) It was regular; (4) It was constructed on the numerical plan of five; (5) Its parts were all distinct or ununited and separately inserted on the receptacle.

To this plan or type the flower conforms in most respects, but deviates slightly, as has been seen, in some: in the partial disappearance of one whorl of stamens; in the growing together of the basal parts of the filaments; and in the partial union of the carpels of the gynœcium.

(2) *Deviations from the Type.*—Comparing the flowers of different dicotyls with the type, various kinds of deviations from it are found.

(*a*) *The numerical plan is often different.* By far the commonest number among dicotyls is the number five; but not infrequently the number four is met with, as in the Cruciferæ, the Oleaceæ, and many of the Rubiaceæ; sometimes the number two, as in the Papaveraceæ and the Fumariaceæ; and sometimes the number six, as in some of the Berberidaceæ.

In some instances there is such an excessive multiplication of parts, or, on the other hand, such an extreme reduction of them, that the original numerical plan is obscured. Instances of the former occur in the Water Lilies and Cactaceæ, and of the latter in the Willows.

It is probable that in some instances of deviation from the number five the deviation has come about by a reduction of the number of parts. For example, in the genus Sedum tetramerous flowers are often found in the same cluster with pentamerous ones, and there can be little doubt that the tetramerism has been brought about as a gradual modification from the pentamerous type.

It would be unsafe to conclude, however, that all flowers of dicotyls were originally constructed on the plan of five.

(*b*) *The whorls are often diminished in number.* The most commonly omitted whorl, perhaps, is the outer or inner whorl of

stamens; but the flower may be defective in any of the other whorls, or even in several of them. It may be reduced, in fact, to a single whorl, or even to a single floral leaf. Thus, there are flowers with pistils only; those with stamens only; those without either stamens or pistils; those with both, but without floral envelopes; those which consist of a single stamen or of a single pistil; and so on.

(*c*) *The whorls are often increased in number.* This may apply to any of the floral organs, and may occur naturally or may be produced artificially. In the Buttercup and Strawberry, for example, the stamens and pistils are multiplied excessively, while the sepals and petals conform to the number five.

"Double" Roses, Buttercups, and Camellias are examples of deviations of a similar nature brought about by a high degree of cultivation.

(*d*) *The parts frequently grow together.* A tendency of this kind has been seen in the stamens and pistils of the Flax, but it is carried much farther in many other flowers. Either organs of the same kind may unite, as in the Morning-glory, where the five petals are merged into a single funnel-shaped organ, or organs of different kinds may unite more or less, as when the stamens are borne in the corolla-tube in the Phlox, or the stamens and pistils adhere, as in the Milkweeds.

(*e*) *The parts may be irregular.* Deviations of this sort are exceedingly common, and may occur in any organ of the flower, though those which most commonly show irregularities of size, shape, or color are the calyx and corolla. There may be only a slight difference in color, shape, or size among organs of the same whorl, or some one or more of them may be markedly different from the rest, as in the spurred sepal of the Larkspur or the spurred petal of the Violet.

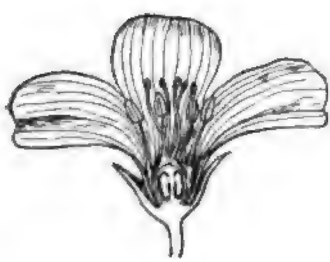
(*f*) *There may be anteposition instead of alternation of parts.* The petals may be inserted directly in front of the sepals, or the stamens in front of the petals, or the pistils in front of the stamens; all or any of these varieties of dissymmetry may occur in a single flower. Deviations of this sort come about sometimes by the suppression of a whorl. If, for example, there were originally two whorls of stamens in a symmetrical flower, the suppression of the outer one would leave the inner one opposite

the petals. Doubtless most deviations of the kind may be explained in this way, but sometimes they are due to the consolidation of two whorls into one, as is probably the case in some members of the Barberry family.

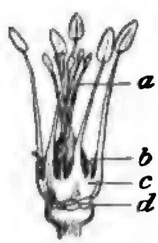
As a practical point of much importance to the beginner, it is to be noted that flowers constructed on the numerical plan of three are much the commonest among monocotyls and seldom occur among dicotyls.

The student should now study and make drawings of one of the other flowers mentioned at the beginning of this exercise.

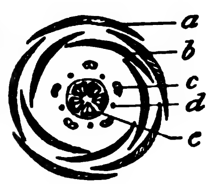
1



2



3



4

PLATE XVII., FIG. 1.—Upper part of Flowering Stem of Flax (about ⅔ natural size).

FIG. 2.—Longitudinal Section of one of the Flowers (somewhat enlarged).

FIG. 3.—A Flower with the Sepals and Petals removed, showing andrœcium and gynœcium: *a*, one of the styles; *b*, staminode; *c*, short staminal tube; *d*, scars left by removal of floral envelopes.

FIG. 4.—Ground Plan of Flower: *a*, sepal; *b*, petal; *c*, stamen; *d*, staminode; *e*, ovary in cross-section.

EXERCISE XIV.

STUDY OF THE FLOWER OF A RANUNCULACEOUS PLANT.

SELECTIONS may be made from any of the following: Goldthread (Coptis trifolia, *Salisb.*), any one of the Buttercups (as, for example, the Common Ranunculus septentrionalis, *Poir.*), the Marsh Marigold (Caltha palustris, *L.*), the Columbine (Aquilegia Canadensis, *L.*), the Larkspur (Delphinium consolida, *L.*), or the Monkshood (Aconitum Napellus, *L.*). The last two are cultivated in gardens, while the rest are all common native plants.

A selection is made of the Goldthread, a beautiful little plant exceedingly common in the bogs of our northern forests, where it grows among the moss. It is called Goldthread because its long, slender, creeping rhizomes, not more than a millimetre in diameter, are golden yellow in color. At intervals of about an inch these rhizomes bear minute scales occurring alternately, and from near these issue numerous very delicate adventitious roots, also golden yellow in color. In flowering-time, which occurs in May, two long-petiolate, exstipulate, radical leaves may be observed, which are ternately divided, with obovate-cuneate, serrate, and somewhat trilobate segments. These leaves have persisted over winter, and are smooth, deep glossy-green above, paler below, and lie spread out upon the moss. At this time two other leaves, upright and in the process of unfolding, are also to be seen, and from between these rises the slender scape, bracted above its middle and terminated by a single white flower.

(1) The flower is studied first *with reference to its parts.* Careful scrutiny shows that there are, as in the typical flower already studied, four kinds of floral organs: an outside whorl, imbricately arranged, and consisting usually of five distinct pieces (though the number varies sometimes to six or seven); a second whorl of club-shaped bodies, each hollow and with a small aperture at the top; a circle, or rather several circles, of distinct stamens, the number varying between fifteen and twenty-five; and in the

centre a whorl of pistils, frequently five in number, but often varying from three to seven.

(2) *The Calyx.*—The exterior whorl, from its color, looks like a corolla, but is really to be regarded as a calyx, because the whorl of club-shaped bodies next interior occupies the place of the corolla and must be regarded as such. The calyx in this case illustrates the not uncommon fact that this organ may become corolla-like, and take the place of a corolla in its function of making a show for the attraction of insects.

(3) *The corolla* in this flower has become even more modified. It is no longer showy, and, as has been seen, its petals have not the usual shape. Indeed, they serve an altogether different function from the ordinary one; they are, in fact, nectaries, or repositories of sweet secretions. The change from the ordinary form of a petal will be understood better if a comparison be made of these petals with those of a true Buttercup. Figure 4 (Pl. XVIII.) represents a petal of Ranunculus repens with a nectary at its base. One may easily believe that the Coptis, a close relative of the Buttercup, once had similar petals, and that these in time have become reduced until now nothing is left of them but the nectary.

(4) *The Floral Symmetry.*—So far, however, the flower conforms very well to the dicotyl pattern-flower already studied, for the two whorls are each usually pentamerous and alternate with each other. The stamens, though, present a deviation from the type which is almost universal in the Ranunculaceæ and which occurs also in some other orders—namely, they are *indefinite* in number, representing perhaps from three to five or more whorls. The flower is unsymmetrical, therefore, as respects the stamens.

The pistils, while showing more tendency to variation in number than either sepals or petals, may still be regarded as conforming to the type, since not infrequently their number is five, and since, as in the other members of this order, they are distinct from each other.

(5) *Distinctness of Parts.*—Another characteristic which this flower has in common with nearly all the members of the order to which it belongs is the absence of any union of its parts. Not only are the parts of the same whorl all distinct or separate from each other, but all of the parts are separately inserted on the

receptacle; that is, there is no union of parts belonging to different whorls. The Columbine and a few other members of the order are slightly exceptional in the fact that their pistils are partially united at their base.

(6) Studying now the floral organs individually, it will be found that the sepals are short-stalked or clawed, elliptic-lanceolate in outline, acutish or somewhat obtuse at the apex, spreading when the flower is in full blossom, and each five or six millimetres in length.

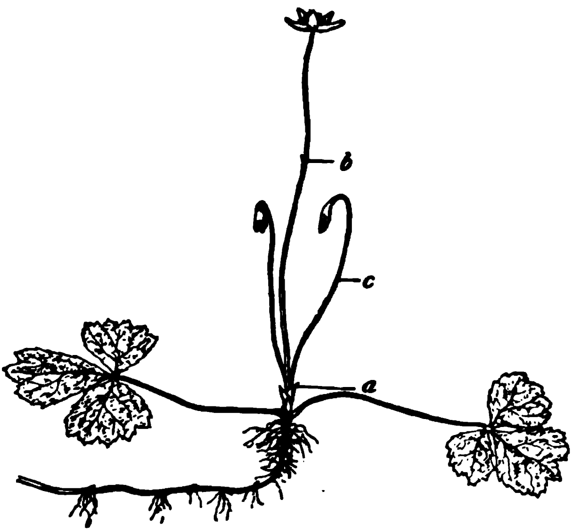
The petals are less than half as long, and somewhat resemble large stamens.

The stamens have filiform stalks or filaments and two-lobed anthers. The base of each anther is inserted directly on the end of the filament—a position which is described as *innate*—and each lobe opens to shed its pollen by means of a longitudinal slit on the side. Since, therefore, the anthers face neither inward nor outward, they are described as *lateral.*

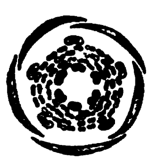
Each pistil is stalked or *stipitate,* a rather unusual thing in pistils, but one which one should expect would occasionally occur, since a pistil is derived from a leaf. There is a short style, and a relatively long recurved stigma which is stigmatic along its ventral side only.

Making a cross-section through the ovary, it will be found that there is a double row of ovules on the ventral side, as shown on Plate XVIII. (Fig. 3, *e*). The pistil is in fact a simple one, representing a single modified leaf—a leaf so rolled up that its ventral surface and its edges are interior, and having the ovules borne on these internal edges, which thus constitute the placenta.

On opening one of the pistils lengthwise the small ovules will be observed arranged very much as are peas in a pod. They are, however, individually too small to admit of the structure being studied with an ordinary magnifier.

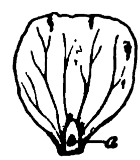


1



2

3



4

PLATE XVIII., FIG. 1.—Plant of Coptis trifolia (⅔ natural size): *a*, scales at base of young leaves and scape; *b*, bract on scape; *c*, one of the young leaves.

FIG. 2.—Ground Plan of Flower.

FIG. 3.—A sepal, *a;* a petal, *b;* a stamen, *c;* a pistil, *d;* and the cross-section of the ovary, showing placentation, *e*.

FIG. 4.—Petal of Buttercup, showing nectary, *a*, at its base.

EXERCISE XV.

STUDY OF A DIMEROUS FLOWER.

Any of the following plants bear flowers that may be studied to advantage: the Bloodroot (Sanguinaria Canadensis, *L.*), the Celandine (Chelidonium majus, *L.*), the Poppy (Papaver somniferum, *L.*), the Prickly Poppy (Argemone Mexicana, *L.*), the Climbing Fumitory (Adlumia cirrhosa, *Raf.*), the Dutchman's Breeches (Dicentra cucullaria, *DC.*), or the Pale Corydalis (Corydalis glauca, *Pursh*).

For this study the first in the list is chosen. The Bloodroot is a very common herb found in rich woods throughout the Northeastern United States and Canada. Its conspicuous white or pinkish blossoms are among the most prized of our early spring flowers, and its short, thick rhizomes are useful in medicine. The whole plant contains a copious orange-red milk-juice which is very acrid to the taste, and the color of which has given origin both to the common and to the first part of the scientific name of the plant.

I. Subterranean Parts.—The rhizomes are reddish-tinged on the outside, from four to six centimetres in length and from ten to twelve millimetres thick, are nearly circular in cross-section, somewhat enlarged at intervals of about one centimetre, distinctly annulate, with rather faint stem-scars on the enlargements on the upper surface, and provided with rather numerous nearly simple adventitious roots that spring chiefly from the sides and lower surface, but occasionally also from the upper. The rootlets have the same color as the rhizome, and are from one to one and a half millimetres in thickness at their base.

The rhizome, when mature, sends out from lateral buds from one to several branches which are relatively thin at the point of attachment to the main body. Not infrequently an old rhizome may be found with five or six of these branches attached to it, each producing a leaf or leaves and a flower-stalk. Ultimately,

though, the parent rhizome dies, setting the branches free, so that the latter become independent plants.

A cross-section of the rhizome shows a thin cortex and a very thick and large-celled pith, and these are separated from each other by a narrow circle of vasal bundles. The rest of the structure is destitute of lignified tissue, and even the bundles contain but little. Pith and cortex are thickly studded with secretion-cells which contain the red milk-juice already referred to.

At the end of the rhizome or of a branch, and well toward the lower side, is the scaly terminal bud from which spring the aërial stem and leaves. At the base of this, on the lower side and in the axil of one of the lower scales, is a minute bud destined to continue the growth of the underground stem.

II. ABOVE-GROUND PARTS.—From each terminal bud there arises in early spring a single erect leafless stem about twelve centimetres high which is terminated by a single flower. A stem like this, which bears flowers only, is called a *scape*. The lower bracts of the bud develop but slightly, the upper ones considerably, so that the latter rise two or three inches above the soil. The bud contains also in its interior usually two true leaves, one of which emerges from the bud, but does not fully unfold at the time of flowering, while the other does not make its appearance until considerably later.

(1) *The leaves* are long-petiolate, and, since they spring from underground parts, are called radical leaves. They are smooth and glaucous on both surfaces. The blades are nearly orbicular, deeply cordate at the base, and palmately lobate on the margin. The venation forms a fine example of palmate reticulation, the veins being quite prominent on the lower surface.

(2) *The Flower.*—In order to get a complete knowledge of the floral structure it is necessary to study it in different stages of anthesis. In an early stage, when the flower first emerges from the protection of the convolute leaf-blade, the two greenish sepals fall away. Sepals or other foliar organs which thus early disappear are called *caducous*. The petals are usually eight, but sometimes twelve, sixteen, or even more, are either pure white or tinged with pink, and are apparently arranged in whorls of two, the outer and broader whorl alternating with the sepals, the next pair with the first pair of petals, and so on. The sepals are oval or ovate

in outline and a little more than half as long as the petals. The outer petals are lance-oval or lance-ovate, obtuse, and about three millimetres in length. The inner petals are much narrower than the outer ones.

The stamens are numerous, usually from sixteen to thirty-two, and are probably to be regarded as being arranged in successive whorls of two, though they are so crowded that the fact is not evident from inspection. The stamens are not of equal length, the inner being longer than the outer.

Each stamen consists of a white thread-like stalk or filament and an oblong, somewhat curved, two-lobed, adnate, and extrorse anther which dehisces longitudinally.

All the parts of the flower thus far considered are distinct from one another and separately inserted on the convex receptacle.

The pistil, however, consists of two leaf-elements or carpels united. This is shown not only by the distinctly two-lobed stigma and the more or less two-lobed ovary, but by the internal structure, presently to be studied.

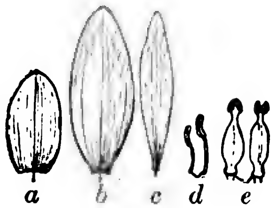
Except the papillose yellow stigma, the pistil is glaucous and green. The style is short and erect; the ovary is somewhat flattened, with two faint ridges running from base to stigma along its margins, and is inserted directly on the top of the receptacle.

A cross-section reveals the fact that the ovary is one-celled and that the numerous ovules are anatropous and arranged in two opposite vertical rows on the ovary-walls. That is to say, the placentation is marginal.

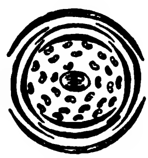
Although the fact that the ovules are anatropous might be made out with an ordinary magnifying glass, it can more easily be done later on, when the pistil has ripened, or nearly so, into a fruit.

It is clear from our study that the numerical plan of this flower is that of two; it is therefore *dimerous*. All the different organs of a flower are represented; it is therefore *complete*. All the petals are distinct or ununited; the flower is therefore *choripetalous*. And the stamens are not attached to any other floral organ, but are directly inserted upon the receptacle below the pistil; they are therefore *hypogynous*.

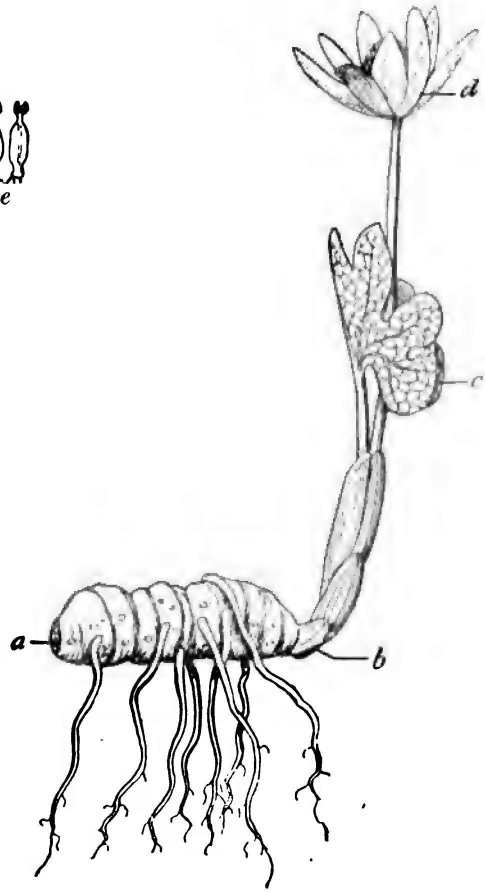
Drawings should now be made showing (1) the plant as a whole when in the blossoming stage, (2) the separated parts of the flower, and (3) a ground plan of the flower.



2



3



1

PLATE XIX., FIG. 1.—Whole Plant of Bloodroot (natural size): *a*, rhizome with its ring-like scars and rootlets; *b*, one of the lower bud-scales; *c*, imperfectly-developed leaf-blade; *d*, the fully-expanded flower, the calyx having fallen away.

FIG. 2.—Different Parts of Flower (⅔ natural size): *a*, sepal; *b*, one of the outer petals; *c*, one of the inner petals; *d*, two of the stamens—the one to the left an outer one, and the one to the right an inner one; *e*, pistil viewed from different directions.

FIG. 3.—Ground Plan of Flower.

EXERCISE XVI.

STUDY OF A CRUCIFEROUS FLOWER.

Any one of the following plants would serve the purpose well: Rock Cress (Arabis lyrata, *L.*), Toothwort (Dentaria laciniata, *Muhl.*), Spring Cress (Cardamine rhomboidea, *DC.*), Horse Radish (Nasturtium Armoracia, *Fries*), Rocket (Hesperis matronalis, *L.*), Charlock or Field Mustard (Brassica Sinapistrum, *Boiss.*), or Black Mustard (Brassica nigra, *Koch.*). All are common plants, and some one of them may be found in blossom in any portion of the growing season.

The first in the list is made the subject of the present study. Arabis lyrata is a not uncommon herb in sandy or light soil, and blossoms in early spring. It grows to the height of from four to eight inches, has a well-developed tap-root, a rosette of radical leaves which are lyrately pinnatifid and spread out flat upon the ground, a stem which branches more or less, is pubescent below like the radical leaves, and is smooth above, bears alternate, entire, linear-lanceolate, smooth leaves, and terminal or sometimes axillary racemes of white flowers.

(1) *Anthotaxy.*—In some species of plants the flowers occur singly, either at the end of the stem or in the axils of ordinary leaves, while in others they are clustered, and among flower clusters there is a great variety. The arrangement of flowers, including the various modes of clustering, is called *anthotaxy*; and, since the anthotaxy is usually the same in the same species of plant, its study is of importance in the identification of species. There are two principal types of anthotaxy, the *indeterminate* and the *determinate*, and there are several varieties of each. In the indeterminate type the flowers of the cluster develop in succession from the base of the floral axis toward its apex, the oldest blossoms being lowest down on the axis, the youngest next its apex. In the determinate type the arrangement is the precise reverse of

this; that is to say, the unfolding of the blossoms takes place from the apex of the axis toward its base, and the oldest flower is at the apex. If the clusters are compact, and particularly if flat-topped, the flowering in the first type will proceed from the margin toward the centre of the cluster, and in the latter from the centre toward the margin. The two types are therefore often called *centripetal* and *centrifugal* respectively.

Inspecting the anthotaxy of Arabis, it will be found that the flowers occur in succession along a lengthened axis, the oldest at the base. The cluster is therefore indeterminate or centripetal. It will be observed, moreover, that the floral axis is lengthened and that the individual flowers have stalks or pedicels of their own. This is therefore the kind of indeterminate anthotaxy that is called a *raceme*, a very common variety of flower cluster. A peculiarity will be observed in this raceme—namely, there are no small modified leaves or bracts at the base of the pedicels, as is most commonly the case in racemes. The racemes, in fact, are bractless almost throughout the family of plants to which this one belongs. Had the flowers been sessile or without pedicels on the lengthened axis, the cluster would have been called a *spike;* had the flowers been sessile and also arranged on a very short axis, the cluster would have been called a *head;* had either the spike or the head been fleshy and subtended by a conspicuous and more or less showy bract or *spathe*, the cluster would have been called a *spadix;* had the flowers been arranged as in a spike, but each subtended by a scaly bract, the cluster would have been called a *catkin* or *ament;* had the axis been somewhat shortened and the lower pedicels lengthened so as to form a somewhat flat-topped cluster, it would have been called a *corymb;* and had the axis been reduced almost to a point while the pedicels remained long, the cluster would have been called an *umbel.* Racemes, spikes, corymbs, and umbels may also be more or less branching, and hence called *compound.*

(2) *Numerical Plan and Symmetry of the Flower.*—Inspection of a flower of Arabis will disclose a circle of four small greenish sepals, all distinct, nearly alike, and arranged in a circle; alternating with these, four much larger, distinct, and similar white petals; a circle of six distinct stamens, four of them longer than the other two; and a single two-celled and clearly two-carpeled pistil. The

two outer and smaller stamens are inserted on the receptacle slightly lower down than the other four, and hence one may conclude that they are members of a different whorl. The four inner and larger stamens also occur in pairs, each pair occupying the interspace between two of the petals. It might be concluded from this, especially as in some species of the family the filaments of each pair are found united at the base, that each pair is formed by the division or branching of a single stamen. Is, then, the numerical plan of the flower that of two or that of four? This is one of the botanical questions which cannot be answered offhand, but which, if answered at all, can be safely done only by the most careful study of the floral structure. There is reason to believe, from a study of the arrangement of the woody bundles that pass from the stem into the respective floral organs, that the flower originally had at least five whorls—one of sepals, one of petals, two of stamens, and one of pistils—and that the number in each whorl was at least four, or even probably five. It is reasonable to suppose that changes in the original plan have been brought about by the visits of insects, the number of the parts of the flower having thus become modified and reduced to the present limits.

It is remarkable that throughout the family—which, by reason of the cross-shaped appearance of the flowers, is called the Cruciferæ—there should be such a close resemblance in the floral structure. Whenever one meets with a four-sepaled and four-petaled flower having tetradynamous (that is to say, two short and four long) stamens and a two-celled pistil, all separately inserted on the receptacle, one may be certain that the plant bearing it is a member of the natural order Cruciferæ.

(3) *Stamens and Pistil.*—Examining the stamens particularly, it will be found that the anthers are inserted by their bases directly on the ends of the filaments. The anthers are therefore called *innate*. They are also *introrse*, or face inward toward the pistil, and they dehisce longitudinally.

The pistil has a short thickish style, a slightly convex, capitate stigma, and a somewhat flattened ovary. Making a transverse section of the latter, it will be observed that it is two-celled, but the insertion of the ovules is different from that in most plurilocular ovaries—namely, the ovules are borne at the junction of the partition with the walls, and not in the centre or axis

of the ovary. This also aids in distinguishing the Cruciferæ from other plants.

Let the student now study and make drawings of the flower of some other cruciferous plant.

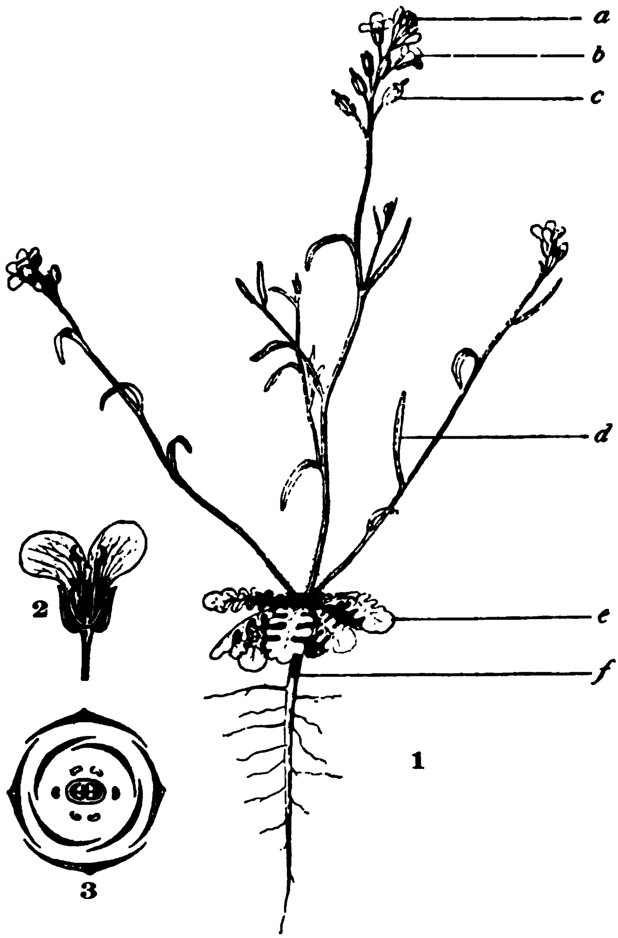


PLATE XX., FIG. 1.—Arabis lyrata, entire plant (⅜ natural size): *a*, upper flower-bud of one of the racemes; *b*, a fully-opened flower; *c*, an older flower from which the petals and stamens have fallen; *d*, one of the cauline leaves: *e*, one of the radical leaves; *f*, the tap-root.

FIG. 2.—Vertical Section of one of the Flowers (enlarged), showing insertion of parts.

FIG. 3.—Ground Plan of Flower.

EXERCISE XVII.

STUDY OF A ROSACEOUS FLOWER.

SELECTIONS may be made from the following common plants: the Strawberry (Fragaria Virginiana, *Mill.*), the Cinquefoil (Potentilla Canadensis, *L.*), the Prairie Rose (Rosa setigera, *Michx.*), the Smooth Rose (Rosa blanda, *Ait.*), the Dog Rose (Rosa canina, *L.*), the Wild Red Plum (Prunus Americana, *Marshall*), the Cultivated Cherry (Prunus avium, *L.*), the Blackberry (Rubus villosus, *Ait.*), and the Dewberry (Rubus Canadensis, *L.*).

For this study the commonly cultivated Bird Cherry (Prunus avium) is selected.

The flowers of this tree spring from axillary buds of the previous autumn, and occur either singly or in umbel-like clusters of from two to five, as shown on Plate XXI. (Fig. 1). On the same twig may be seen the leaf-buds with the conduplicately-folded leaves in the process of unfolding.

(1) *The flower as a whole* may be described as hermaphrodite, complete and regular, but not wholly symmetrical, the gynœcium, and frequently the andrœcium, deviating more or less from symmetry. The flower being showy and white, perfumed, and possessing adhesive pollen, the conclusion is reached that it is *entomophilous*.

(2) *The calyx* may be regarded as gamosepalous with a cup-shaped tube and a five-parted limb. It is so regarded by many botanists, but others view the cup not as the calyx-tube, but as a hollow receptacle from the margin of which spring the five distinct sepals. The calyx-lobes (or sepals) are oblong, obtuse, greenish, and valvately arranged in the bud.

(3) *The corolla* consists of five somewhat obcordate or nearly round, white, short-clawed, spreading petals, about fifteen millimetres long and inserted on the throat of the calyx (or, as some view it, on the margin of the receptacular tube). The preflora-

tion of the corolla is quincuncial, and the petals when expanded are concave on their upper surface.

(4) *The andrœcium* consists of numerous stamens which, like the petals, are perigynously inserted—that is, carried up above the level of the insertion of the pistil on the border of the calyx-tube. There are frequently fifteen or twenty stamens, indicating the presence of four or five whorls in normal flowers; but in this and in most instances where the stamens are numerous their number also varies, and it is common, therefore, to describe the stamens in this and similar cases as *indefinite*.

Each stamen consists of a slender, straight, and rather rigid filament, about as long as, or a little longer than, the petals, and crowned by an oval, somewhat versatile, two-lobed, two-celled, and introrse anther which dehisces longitudinally.

(5) *The gynœcium* consists of a single, one-carpeled pistil which is complete, possessing all the parts of a pistil. The ovary is one-celled, two-ovuled, with a marginal placentation and pendulous, anatropous ovules. The style is erect or slightly bent, filiform, about as long as the filaments, and bears at its apex a slightly concave and somewhat cordate or two-lobed stigma.

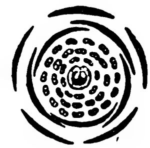
The flowers of the Rosaceæ, the order to which the Cherry belongs, differ among themselves in many minor points, as in anthotaxy, color, size, number of stamens, in the fact that the pistils in some cases are distinct, in others more or less united, in the number of pistils, and even in the adnation of the calyx-tubes. As respects the latter point, in some species the tube grows fast to the walls of the ovary, as in the Apple, for example, while in others it remains wholly free, as in the Cherry and Peach. The flowers are sometimes even diclinous by the abortion of the stamens in some specimens and the pistils in others, but they all agree in their pentamerism and in the perigyny of the petals and stamens.

In appearance the flowers of the Ranunculaceæ often closely resemble those of the Rosaceæ. For example, one of the Hellebores, a poisonous ranunculaceous plant, is so nearly like a Rose in its blossom that it goes by the common name of "Christmas Rose;" and what young botanist has not mistaken a Potentilla for a Buttercup? In both the flowers are pentamerous; in both all the parts are distinct or ununited, the stamens and pistils in-

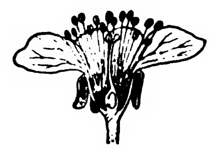
definite, and the flowers yellow with spreading corollas. But in the Potentilla the stamens and petals are perigynous, while in the Buttercup they are hypogynous.

This illustrates the fact, so often met with in natural history, that structural characters are vastly more important in determining relationship than are mere superficial resemblances. In fact, the latter are often very misleading.

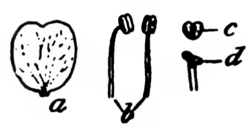
1



2



3



4

PLATE XXI., FIG. 1.—Twig of Prunus avium, *L.* (⅗ natural size).

FIG. 2.—Ground Plan of Cherry Blossom.

FIG. 3.—Vertical Section of Cherry Blossom, showing perigynous corolla and stamens.

FIG. 4.—Parts of Flower: *a*, one of the petals (⅗ natural size); *b*, a stamen in different views; *c* and *d*, different views of the stigma.

EXERCISE XVIII.

STUDY OF A PAPILIONACEOUS FLOWER.

THE plants of the very numerous sub-order Papilionaceæ of the natural order Leguminosæ all have papilionaceous flowers. Good ones for study are the following: the Sweet Pea (Lathyrus odoratus, *L.*), the Scarlet Runner (Phaseolus multiflorus, *Willd.*), the Marsh Vetchling (Lathyrus palustris, *L.*), the Common Pea (Pisum sativum, *L.*), the Wistaria (Wistaria sinensis, *DC.*), the Locust (Robinia Pseudacacia, *L.*), the Lupine (Lupinus perennis, *L.*), and the Broom (Cytisus scoparius, *Link*).

The first of these is selected for the present study.

I. EXTERNAL CHARACTERISTICS.—(1) Observe, first, that the stem differs from the usual form of stems in being strongly flattened or wing-margined. Its surface, like that of the other parts, is pubescent and somewhat glandular. It is herbaceous, and the plant has the scandent habit, climbing by means of tendrils which are modified leaflets of the compound leaf.

(2) The leaves are alternate and stipulate, with ovate-lanceolate, acuminate, half-sagittate stipules; the petioles are wing-margined, and the blade consists of a single pair of ovate-lanceolate, entire, or slightly wavy-margined leaflets and of from three to five others developed into tendrils.

(3) The showy, sweet-scented flowers occur in long-peduncled, few-flowered racemes, with only two or three flowers in a cluster, or they are sometimes solitary. They occur in the axils of the upper leaves.

(4) Draw a portion of the plant, about six or eight inches of its upper end, and point out the stem, a stipule, a petiole, a tendril, an unopened flower-bud, and a fully-expanded flower.

II. STRUCTURE OF THE FLOWER.—(1) *Irregularity.*—One of the most striking things about the flower is the irregularity in its shape. From a fancied resemblance to a butterfly, it has been called *papilionaceous.* Like most irregular flowers, it faces later-

ally or to one side, and not vertically. Various of its parts are more or less irregular. The gamosepalous, five-toothed, somewhat campanulate calyx shows irregularity in the fact that it has a one-sided insertion on the receptacle, and also in the fact that the upper teeth are somewhat shorter than the other three, the lower segment being longest of all.

The corolla is still more irregular both in the relative size and in the shape of its parts. While the calyx-lobes are somewhat irregular, they are still so nearly alike in size that they are found quite regularly imbricate in the bud; but the petals even in the bud show that peculiar kind of irregularly imbricate æstivation which is called *vexillary* and which is indicated in the ground plan on Plate XXII. (Fig. 4). Examining the petals of the fully-opened flower, the upper one is found much larger and more showy than the rest. It is called the *vexillum*, or standard. The two lateral ones, similar to each other, but different from the rest, are called *alæ*, or wings, and the two lower, partially united to form an organ which resembles the keel of a boat, have hence been called the *carina*, or keel.

The stamens also show some irregularities. These organs are ten in number, originally, probably, in two whorls of five each, but now appearing as one. Nine of them are somewhat unequally united by their filaments for more than half their length, while the other one, the upper one in the ordinary position of the flower, is distinct. They are also somewhat unequal in length.

The simple pistil is also slightly irregular in the fact that the style is bent abruptly upward near its origin. It is also bearded along the inner side only.

(2) *Dissymmetry.*—The numerical plan of the flower is clearly that of five, the calyx and corolla agreeing with this number and the stamens being a multiple of it. Moreover, the petals alternate with the teeth of the calyx, and, as has been seen, the stamens are probably to be regarded as in two alternating whorls of five each. So far, therefore, the flower is symmetrical. But in the pistil is found a deviation, for there is but one instead of the expected number five.

(3) *Cohesion.*—It has already been observed that the calyx is gamosepalous, the two sepals being united for about one-half their length. The corolla is regarded as choripetalous, since the petals

are distinct at the base, though those forming the keel are united toward the apex. The stamens—forming as they do two groups by the union of the filaments of nine of them, while the other one remains distinct—are described as *diadelphous*.

Since the flower is on the numerical plan of five, one would naturally expect to find either five distinct pistils or else one compound pistil composed of five united carpels. Is the one pistil which is present one-carpeled or five-carpeled? This question can be answered only by studying the structure. Observing the stigma, it will be found to be entire, and not at all lobed or divided. This is evidence, so far as it goes, of a one-carpeled pistil. But there must be additional proof. Making a cross-section of the ovary, this is found to be only one-celled, and, what is more to the point, it is seen that the ovules form a double row along the upper or ventral side of the ovary only. Had there been two double rows on opposite sides, one would have been obliged to regard the pistil as two-carpeled, or, if three, three-carpeled, and so on; but, since there is only one, it must be concluded that it is but one-carpeled, or represents but a single modified leaf. The flower has become unsymmetrical, then, by the loss of four of its pistils.

(4) *Adhesion.*—Making a vertical section centrally through the flower from base to apex, it will be found that the different whorls of floral organs are successively inserted on the receptacle; there is no growing of one floral leaf to another of a different kind, and therefore no *adhesion* nor *adnation*.

(5) Make a drawing of the separated petals, so that their relative shapes and position may be seen at a glance. Point out the vexillum, one of the alæ, and one of the two petals forming the carina.

(6) Draw a vertical section of the flower, showing the succession and mode of insertion of the parts. Point out the calyx, the vexillum, one of the alæ, a petal of the carina, the staminal tube, and the pistil.

(7) Draw a diagram of the ground plan of the flower, and point out the following parts: a sepal, the vexillum, an ala, a petal of the carina, a stamen, and the pistil.

(8) *Significance of the Peculiarities of Structure.*—The showiness of the flower, its agreeable odor, and the fact that it secretes

nectar at the base of its corolla lead one to suspect that the plant makes use of insects, at least occasionally, to secure cross-fertilization. The irregularities in the floral structure are also to be regarded as adaptations to the same end. The large upper petal —and, to a less extent, the two lateral ones—are specialized for show. That the flower faces laterally instead of vertically is explained by the fact that thus the visiting insect is more liable to alight on the flower in such a way as to touch the stigma and also to become dusted with the pollen.

Let us see what occurs when some large hymenopterous insect, such as a bumble-bee, for example, visits the flower. The horizontally projecting keel and wings, particularly the former, afford the bee a most convenient landing-place. The stamens, it should be borne in mind, have two-lobed, introrse, longitudinally dehiscent anthers, which in the undisturbed flower lie in close contact with the upturned portion of the style, immediately beneath the stigma, and the stamens are all enclosed and concealed from view by the keel. The upper end of the style is rigid like the rest of the pistil, and, as has been seen, its front side is covered with numerous stiff hairs which form a kind of brush. The petals composing the keel are united along the lower edges except at the very base, but not on the upper side. Being thin and flexible at the base, if the heavy insect alight upon the keel, the latter will bend downward, and as a consequence the stigma and upper end of the style will protrude from the slit in the upper side. The anthers, however, being borne upon weak filaments, will be retained within the keel, while the downward movement of the latter will cause the hairy style to brush out a portion of the adhesive pollen from the anthers. This, or a part of it, will be carried against the insect's body. The stigma will also necessarily be brought into contact with the insect's body, and if this has previously been dusted with pollen from another flower, some of it will almost certainly be deposited upon the stigma. The protrusion of the stigma and the brushing out of the pollen may easily be demonstrated by simply pressing gently downward on the keel with the thumb and forefinger.

Occasionally, at least, cross-fertilization is thus likely to be brought about, and in the native country of the plant probably habitually so, by certain large hymenopterous insects. In this

country, however, and in England cross-fertilization by insect agency seems to be a rare occurrence, owing probably to the lack of perfect adaptation of the flowers and native insects to each other. The flowers, though, are self-fertilized and seed freely. It is evident that they are so constructed that in case of failure to receive other pollen they can utilize their own. That Nature did not form them, however, for habitual self-fertilization is clearly indicated not only by the structure of the flower as explained above, but also by the fact, observed by Mr. Darwin, that the seeds produced by cross-fertilization develop stronger and more vigorous plants than those produced by self-fertilization.

The student should now study, describe, and draw one of the other Papilionaceæ mentioned at the beginning of this exercise.

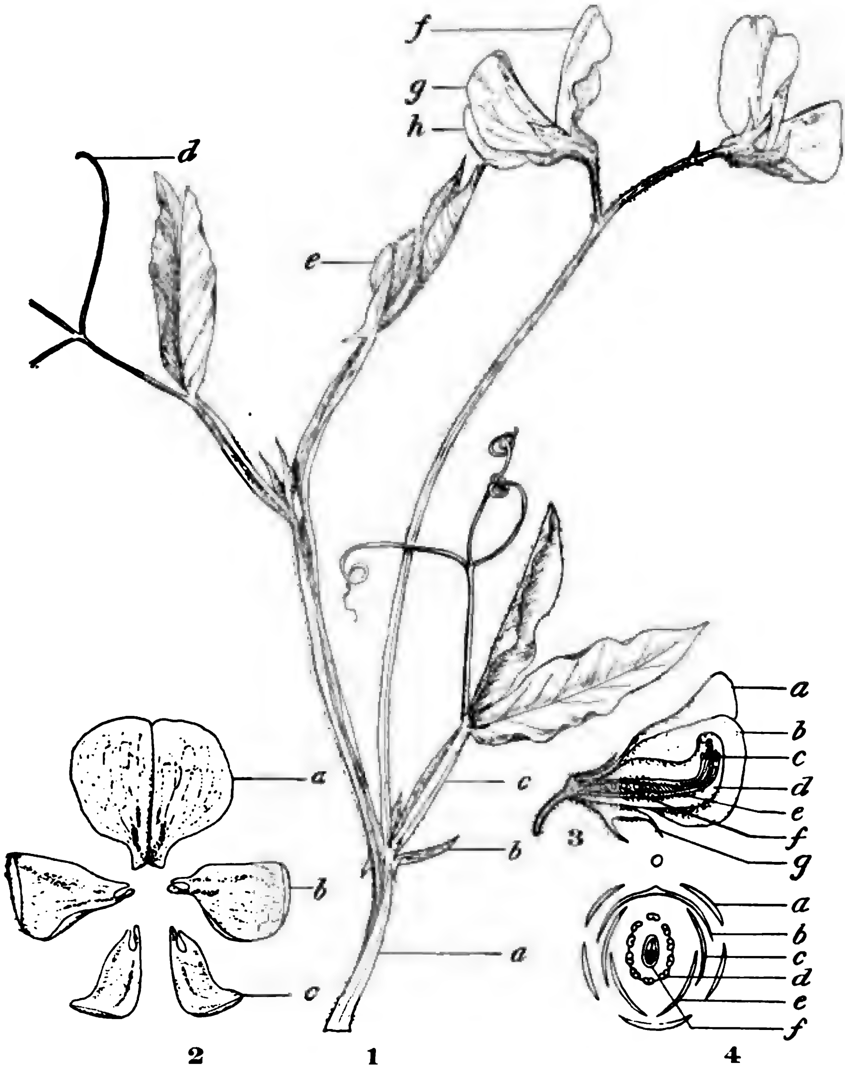


PLATE XXII., FIG. 1.—Drawing of Upper Part of Plant of Lathyrus odoratus (⅔ natural size): *a*, winged stem; *b*, stipule; *c*, flattened or alate petiole; *d*, a leaflet-tendril; *e*, flower-bud, one of a cluster of three; *f*, vexillum, or large upper petal of corolla; *g*, one of the alæ or wings; *h*, carina or keel.

FIG. 2.—The Petals of the Corolla separated so as to show their shapes: *a*, vexillum; *b*, ala; *c*, one of the petals of the carina.

FIG. 3.—Vertical Section of one of the Flowers, showing insertion of parts: *a*, vexillum; *b*, ala; *c*, stamens; *d*, carina; *e*, staminal sheath; *f*, ovary; *g*, calyx-tooth.

FIG. 4.—Diagram of Ground Plan of Flower: *a*, sepal; *b*, vexillum; *c*, ala; *d*, stamen; *e*, petal of carina; *f*, pistil.

EXERCISE XIX.

FLOWER OF A GAMOPETALOUS DICOTYL.

SELECTIONS may be made from the following: the Jamestown Weed (Datura Stramonium, *L.*), the Common Potato (Solanum tuberosum, *L.*), the Ground Cherry (Physalis pubescens, *L.*), the Common Morning-glory (Ipomea purpurea, *Lam.*), the Hedge Bindweed (Convolvulus sepium, *L.*), the Lungwort (Mertensia Virginica, *DC.*), the Wild Phlox (Phlox divaricata, *L.*), the Fringed Gentian (Gentiana crinita, *Froel.*), the Harebell (Campanula rotundifolia, *L.*), the Partridge Berry (Mitchella repens, *L.*), and the Bluets (Houstonia cærulea, *L.*).

The last mentioned on this list is selected for the present study. The Houstonia is a beautiful little plant, abundant in open and moist ground in most parts of the Northern United States, where it blossoms in early spring. Humble and unpretentious as it is, it is a member of the same family of plants as that to which the Coffee and Cinchona trees belong—the natural order Rubiaceæ. The delicate stems are somewhat branching, more or less quadrangular, erect, and rise to the height of from three to five inches. They spring from slender, filiform rhizomes which give rise to even more slender fibrous rootlets. The small, spatulate-oblong radical leaves are petiolate and entire or somewhat toothed. The opposite stem-leaves are smaller and narrower, the upper ones being reduced to linear bracts, and the bases are connected by minute entire stipules. The flowers are solitary at the ends of the main stem and its branches.

(1) *The calyx* is gamosepalous, its tube adherent to the walls of the ovary, and its limb separated into four small, linear, at first erect or ascending, but afterward spreading lobes, which are green and persistent.

(2) *The corolla* is gamopetalous and hypocrateriform, with a tube from five to seven millimetres long, narrow below and larger above. The flowers are of two forms—one with the enlargement

beginning about the middle of the tube and extending to the throat, the other with the enlargement beginning higher up. The color of the tube is whitish or yellowish. The limb is pale lilac or sometimes nearly white, and is parted into four elliptical segments. The throat is yellow.

(3) *The andrœcium* consists of four stamens borne upon the tube of the corolla and nearly sessile.

The anthers are introrse, bilocular, distinct, alternating with the lobes of the corolla, and longitudinally dehiscent. In the two forms of the corolla they are inserted on the tube at different levels—in one near its middle, in the other in the throat.

(4) *The gynœcium* consists of a single bicarpellary pistil composed of an ovary nearly enveloped in the calyx-tube, and a slender, filiform style which in the two different forms differs in length. In that with the stamens inserted near the middle of the tube it rises to the throat, in the other only to about the middle of the tube; that is, the long-stamened form has short styles, and the short-stamened one has long styles.

The stigmas are two-lobed, and the ovary is two-celled, with axile placentation and several ovules in each cell.

(5) *Mode of Cross-fertilization.*—The question naturally arises in the thinking mind, why flowers of two different forms exist within the limits of the same species, as they do in this and in many other plants. Darwin proved this arrangement to be a provision to ensure cross-fertilization by insect agency. Suppose an insect, whose beak or proboscis is just long enough to reach the nectar in the bottom of the corolla, to visit one of the long-styled flowers of this species: the insect's throat will be brought into contact with the stigmas, and the middle portion of its proboscis will be dusted with the adhesive pollen from the introrse anthers, which so nearly close the tube at the level of their insertion that the nectar cannot be reached without contact with them. The same thing will occur, of course, if the insect visits other flowers of the same form, but none of the pollen thus withdrawn will necessarily be deposited upon the stigmas. But when the insect flies away to flowers of the other form the case is different. Here the anthers are so situated as to dust the insect's throat with pollen, while the middle part of its proboscis is brought into contact with the stigmas, dusting them with pollen from the long-styled flowers.

Thus the flower attracts insects by its showy color, rewards them for their visits by the nectar it secretes, and, by the structure of its corolla-tube, together with the proper relative adjustment of the anthers and styles, makes use of them to convey the pollen from the stamens of one plant to the stigmas of another, and so secures cross-fertilization. It is more than probable, also, that the plant, like many other species with dimorphous flowers, prefers pollen from another flower to its own, and only makes use of the latter when that from a flower of the other form cannot be obtained.

The Bouvardia of our greenhouses, a related plant from Mexico, is often available for study when Houstonia is not in blossom. The flowers are also dimorphous, and have a structure quite similar to that of Houstonia. A twig with ground plan and vertical section of a flower is shown on Plate XXIII. (Figs. 4, 5, 6).

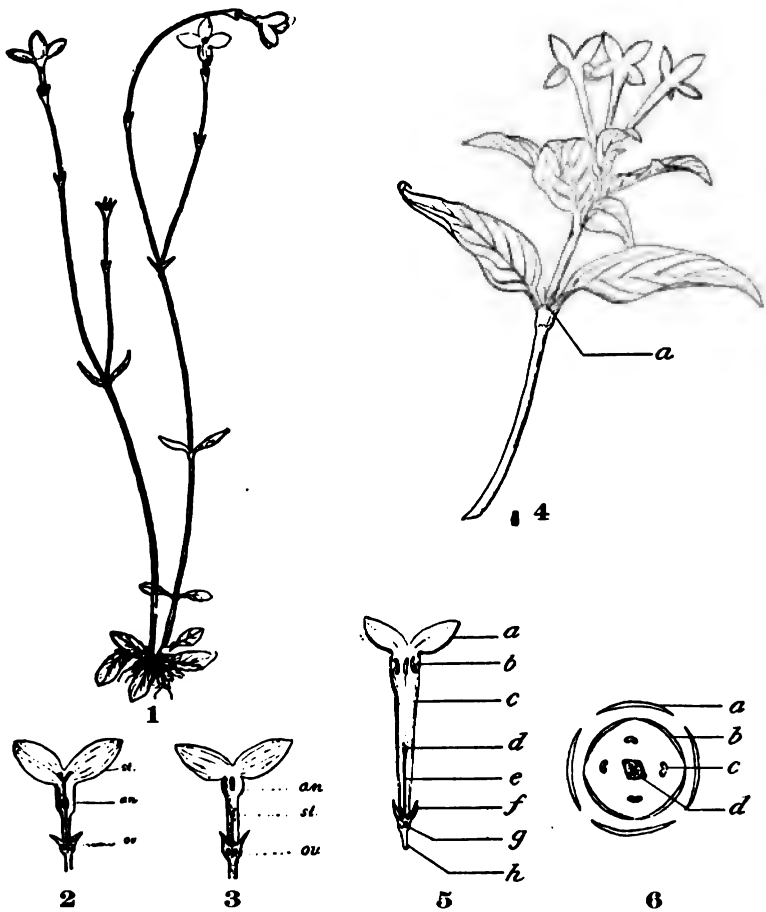


PLATE XXIII., FIG. 1.—Plant of Houstonia cærulea (about $\frac{2}{3}$ natural size).

FIG. 2.—A Long-styled Flower of Houstonia cut vertically to show structure: *st*, stigmas; *an*, anthers; *ov*, ovary.

FIG. 3.—Vertical Section of Short-styled Form of Houstonia, to show internal structure: *an*, anther; *st*, stigmas; *ov*, ovary.

FIG. 4.—Twig of Bouvardia, bearing a cluster of three salver-shaped flowers: *a*, stipule. ($\frac{2}{3}$ natural size.)

FIG. 5.—Vertical Section of one of the Short-styled Flowers of Bouvardia: *a*, corolla-lobe; *b*, stamen; *c*, corolla-tube; *d*, stigmas; *e*, style; *f*, calyx-lobe; *g*, ovary; *h*, peduncle.

FIG. 6.—Ground Plan of Bouvardia Flower: *a*, sepal; *b*, petal; *c*, stamen; *d*, ovary.

EXERCISE XX.

STUDY OF AN ERICACEOUS FLOWER.

SELECTIONS may be made from the following plants: the Common Blueberry (Vaccinium corymbosum, *L.*), the Stagger Bush (Andromeda mariana, *L.*), the Leucothöe (Leucothöe racemosa, *Gray*), the Leather Leaf (Cassandra calyculata, *Don*), the Mountain Laurel (Kalmia latifolia, *L.*), the Pinxter-flower (Rhododendron nudiflorum, *Torr.*), the Prince's Pine (Chimaphila umbellata, *Nutt.*), the Shin-leaf (Pyrola elliptica, *Nutt.*), the Wintergreen (Gaultheria procumbens, *L.*), the Bearberry (Arctostaphylos uva-ursi, *Spreng.*), and the Trailing Arbutus (Epigæa repens, *L.*).

From this list, for the present study, choice is made of the Trailing Arbutus. This exquisite little plant, everywhere a favorite with lovers of flowers, has a wide distribution over the eastern part of North America, being especially abundant, however, in the Alleghenies and in the rugged pine and fir-clad regions bordering the Great Lakes and the St. Lawrence River. It blooms among the earliest of our spring flowers, often sending up its fragrant white- or rose-colored blossoms in close proximity to the lingering snow-drifts in our northern woods. Its shrubby stems are slender, extensively trailing, and covered, as are the petioles and inferior leaf-surfaces, with rusty-brown hairs. The leaves are five or six centimetres long, alternate, evergreen, with slender and rather long-petiolate, elliptical, entire-margined, prominently reticulate blades which are rounded or cordate at the base and mucronate at the apex.

(1) *The flowers* occur in short, almost spike-like racemes at the ends of the stems, and are white or rose-tinged and attain a length of one and one-half, and sometimes even two, centimetres. The pedicels are short, two or three millimetres long, and brown-hairy, as are also the scaly bracts.

(2) *The calyx* is five-parted or with almost distinct sepals which

are lanceolate, entire, nearly smooth, about the length of the corolla-tube, pointed, and scale-like.

(3) *The corolla* is hypocrateriform, the lobes of its five-parted limb alternate with the segments of the calyx, it is hypogynous, and the tube is hairy on the interior. In some the color is white, in others deep-rose, and between them there is every intermediate shade. The lobes are ovate, entire, obtuse, or mucronate.

(4) *The andrœcium* consists of ten stamens apparently in a single whorl, but condensed probably from two.

According to Prof. W. P. Wilson, who has studied these flowers carefully, the plant is really diœcious, though most of its flowers still possess both stamens and pistils. In the pistillate flowers, which are usually rose-colored and smaller than the staminate white ones, sometimes the stamens have wholly disappeared; in others they are present, but in a very abortive condition; in still others they are nearly perfect in form, but still functionless. Moreover, the stamens in the male flowers are not all alike. In some flowers they are short, in others long, in others still of intermediate length, and a corresponding difference is found in the length of the styles. The history of the flower, then, may be summed up as follows: It was first hermaphrodite, and possessed stamens in two whorls of five each, and the stamens of the same whorl, at least, were of the same length in different flowers. It then adapted itself to cross-fertilization by insect agency by becoming dimorphous and later on trimorphous, and perhaps polymorphous, and finally the stamens in some flowers and the stigmas in others became abortive, and it thus reached its present diœcious condition. It is probably only a question of time when the last vestige of stamens will disappear from the pistillate flowers, and of pistils from the staminate ones—a condition which is found really existing in many other flowers at the present time.

Observing the individual stamens, they are found to be inserted at the base of the corolla on the receptacle—a noteworthy fact in the Heath family, as in most other flowers with gamopetalous corollas the stamens are inserted on the corolla-tube.

The filaments are bearded at the base and attenuated toward the apex.

The oblong anthers are versatile, introrse, two-celled, and dif-

fer from those of most other Heaths in dehiscing by longitudinal slits rather than by pores at the apex of the lobes.

The pollen-grains also differ from those of most plants outside this natural order in being composed of a group of four cells, as shown on Plate XXIV. (Fig. 5, *a* and *b*).

(5) *The gynœcium* consists of a single pistil, but it is compound, and shows by its structure that it is composed of five carpels. It thus conforms to the numerical plan of the flower, which, except in those unusual specimens in which the stamens are completely aborted, is that of the typical dicotyl already described.

The ovary in its lower part is faintly ten-lobed, but these lobes are in pairs. The upper part is densely hairy. The erect, rather stout cylindrical style is crowned with a five-lobed stigma which in the pistillate flower is star-shaped when fully expanded, but in the staminate one never opens.

A cross-section of the ovary shows five loculi, an axile placentation, and numerous small anatropous ovules.

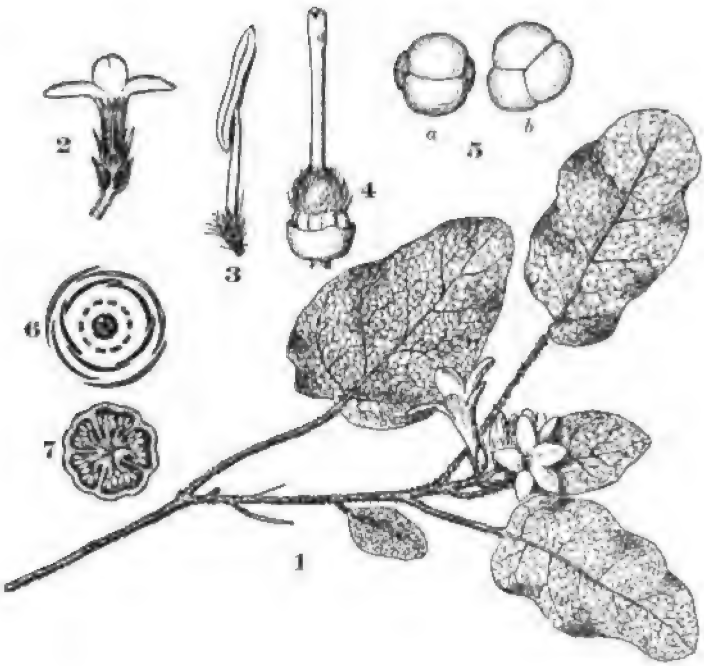


PLATE XXIV., FIG. 1.—A Branch of Trailing Arbutus ($\frac{2}{3}$ natural size).

FIG. 2.—One of the Staminate Flowers in longitudinal section (slightly enlarged).

FIG. 3.—One of the Stamens (magnified 8 diameters).

FIG. 4.—Pistil (magnified 4 diameters).

FIG. 5.—Pollen-grains in clusters of four (magnified 200 diameters).

FIG. 6.—Ground Plan of Flower, showing imbricate calyx and corolla.

FIG. 7.—Cross-section of Ovary, showing its ten lobes in five pairs, its five loculi, axile placentation, and numerous ovules. (Magnified 8 diameters.)

EXERCISE XXI.

STUDY OF A FLOWER OF THE COMPOSITÆ.

THE following species of this natural order are suitable ones for study by beginners: the Common Sunflower (Helianthus annuus, *L.*), the Jerusalem Artichoke (Helianthus tuberosus, *L.*), the Common Beggar-ticks (Bidens frondosa, *L.*), the Sneeze-weed (Helenium autumnale, *L.*), the Ox-eye Daisy (Chrysanthemum Leucanthemum, *L.*), the Burdock (Arctium Lappa, *L.*), the Rattlesnake Weed (Hieracium venosum, *L.*), the Dandelion (Taraxacum officinale, *Weber*), and Chicory (Cichorium Intybus, *L.*).

For the purpose of this exercise a selection is made of the Ox-eye Daisy, an introduced plant now become exceedingly common in most portions of the Eastern United States, where it is regarded by the farmers as a pernicious weed. Besides the common name above given, it is also called in different localities the Marguerite, White Daisy, and White Weed.

It is a perennial herb with ascending, often diffuse, somewhat striate and smooth, branching stems arising from short rhizomes. The lower leaves are rounded, oval, or spatulate, and taper into rather long petioles, and are coarsely toothed, incised, or lobed on their margins; the upper leaves are oblanceolate, lanceolate, or linear-lanceolate, and pinnatifid. They are smooth and deep-green both above and below.

(1) *The anthotaxy* in all the natural order Compositæ is indeterminate, and the flower clusters consist of heads. In many species, however, the heads are cymosely arranged. In this species the heads occur singly at the ends of long, few-bracted peduncles that terminate the main stem and branches.

(2) *The Involucre.*—In the Compositæ the heads are subtended by an involucre consisting of bracts, usually numerous and arranged in one or more circles. In this case the involucre is flattish or slightly convex below and composed of scales imbricated in several rows. The component scales are linear-lanceolate and

scarious on their margins and at their tips. They doubtless represent the bracts of what were in the remote ancestors of these plants a much looser inflorescence, but which in course of time became concentrated into a head.

(3) *The flowers* or florets are individually quite small, and, as in many other of the Compositæ, are of two kinds—marginal ones which are relatively large and showy and are called *ray-flowers*, and interior, smaller, and less showy ones which are called *disk-flowers*. The ray-flowers have ligulate and the disk-flowers tubular corollas. In some Compositæ, as the Dandelion and Chicory, the florets are all of one kind and ligulate, while in others, as in the Burdock and Boneset, they are all tubular.

(*a*) *The common receptacle* on which the florets are arranged is flat or slightly convex and naked; that is to say, no chaff or scales occur upon it among the flowers as they do in many other species of the order. It will be observed that the florets are regularly arranged on the receptacle in spirals.

(*b*) *The ray-flowers* are white, the corolla two-nerved, obscurely two- or three-toothed at the apex, contracted and tubular below, near its insertion on the top of the ovary, and is from ten to eighteen millimetres in length. These flowers are usually in one or two circles, and there are from twenty to thirty of them in each head.

In all the Compositæ the corollas and stamens are epigynous and the tubular calyx (or receptacle) is adnate to the ovary. The calyx-limb, if present, is ring-like, chaffy, bristly or scaly, and is termed a *pappus*. In the present instance it is usually wanting altogether, though sometimes recognizable as a minute scale.

The two-lobed stigma and the upper part of the cylindrical style project from the tubular portion of the corolla as shown on Plate XXV. (Fig. 2), but the stamens are altogether wanting in the ray-flowers.

The ovary is obovoid in outline and longitudinally striate.

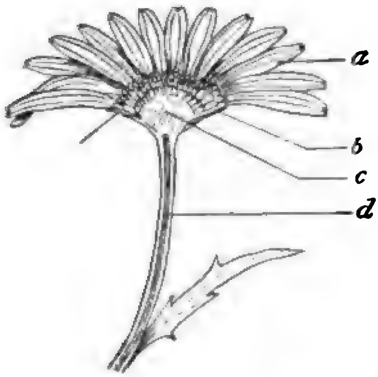
(*c*) *The disk-flowers* are very numerous—often four or five hundred in a single head; they are yellow, with a five-toothed limb the teeth of which are valvate in the bud, and have a tube which is somewhat inflated and bell-shaped above, contracted a little below the middle, and again slightly inflated a little above the ovary. The bottom part of the tube is filled with nectar. The

corolla is much smaller than that of the ray-flowers—only about three millimetres in length. The florets possess both stamens and pistils, the former five in number and united by their enlongated anthers into a tube which surrounds the style. The filaments are thread-like, free, and inserted on the corolla-tube. The anthers are two-celled, introrse, innate, and longitudinally dehiscent.

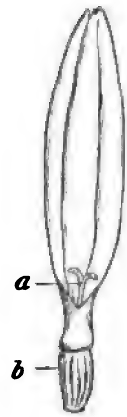
The pistil is similar to that of the ray-flowers. A cross-section of the ovary shows but a single ovule, and a longitudinal section shows that this is erect and anatropous.

The Compositæ are the most numerous in species of all flowering plants, and are among the most highly organized. They are almost without exception entomophilous, sometimes diœcious, more commonly perfect and protandrous. The aggregation of a large number of small flowers in a head is a great advantage, for it accomplishes the purpose of being attractive to the eyes of insects with little expenditure of material for the individual florets. It is also economical in another way: the compact arrangement of the flowers, enabling the insect to sip from a large number in a short space of time and at a single visit, enhances the chances of cross-fertilization.

In most of the order a brush of hairs exists either on the upper part of the style or, as in this species, on the outer sides of the stigma-lobes. Since the style does not complete its growth in length until after the anthers dehisce, its elongation brushes out from the narrow staminal tube the pollen, which emerges along with the still closed stigma at the top of the floret and is gathered up by insects. Later on, the lobes of the stigma open out and expose their stigmatic surfaces to the pollen brought by visiting insects. In this species, and probably in many other Compositæ with perfect flowers, self-fertilization is possible, and probably sometimes occurs, but cross-fertilization, frequently between florets of the same head, but often from flowers of different heads and from other plants of the species, must be habitual. According to Prof. Hermann Müller, as many as seventy-two different species of insects have been observed to visit the flowers of this plant.



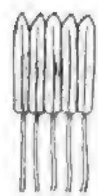
1



2

3

4



5

PLATE XXV., FIG. 1.—Flower-head of Ox-eye Daisy (about natural size), cut longitudinally to show arrangement of parts: *a*, one of the ray-florets; *b*, a disk-floret; *c*, the common receptacle; *d*, the hollow peduncle.

FIG. 2.—One of the Ray-florets (considerably enlarged): *a*, two-lobed stigma; *b*, ovary surmounted by the corolla-tube.

FIG. 3.—One of the Tubular Disk-florets (much enlarged).

FIG. 4.—Pistil with fully-developed Style and Stigma. (Much enlarged.)

FIG. 5.—Staminal Tube laid open and exposing inner face of Anthers.

EXERCISE XXII.

STUDY OF A MONOCHLAMYDEOUS FLOWER.

THE following plants are favorable ones for study: Wild Ginger (Asarum Canadense, *L.*), Pipe Vine (Aristolochia Sipho, *L'Her.*), Buckwheat (Fagopyrum esculentum, *Moench*), Four-o'clock (Mirabilis Jalapa, *L.*), and Pokeweed (Phytolacca decandra, *L.*).

From the above-mentioned is selected for this study the Wild Ginger, a member of the Birthwort family, and a plant which is not uncommon in rich woods in the northern part of the United States, and which blossoms in May. It produces rhizomes which creep extensively near the surface of the ground and which branch frequently as in Podophyllum, giving rise to new plants. These rhizomes are nearly cylindrical or somewhat quadrangular, marked at intervals of about twelve millimetres with prominent, more or less oblique scale-scars, and on their under surface, mostly from the nodes, producing small clusters of slender, nearly simple rootlets averaging about sixty millimetres in length. A cross-section of a rhizome shows a thin circle of wood enclosing a large pith and composed of about twelve short wood-bundles. The iodine test shows it to contain abundance of starch. Besides some bitterness, it is pungently aromatic, reminding one of ginger, hence the popular name of the plant.

The end of the rhizome rises obliquely to form the very short above-ground stem, and this bears two long-petiolate, exstipulate leaves whose blades are broadly reniform, entire-margined, and slightly pointed at the apex. The blades are thin, have a transverse diameter of from ten to twelve centimetres, are deep-green and silky lustrous by reason of a minute pubescence on the upper surface, and are lighter colored and prominently veiny below.

From between the two leaf-bases issues a single pedunculate, nodding, dull-purple flower, which, together with the peduncle, is densely covered on the outside with a woolly pubescence.

(1) *The calyx* is rather fleshy, with a tube adnate to the ovary, and a three-parted limb the segments of which, in the bud, have their tips inflexed, but which are wholly recurved when the flower is in full blossom.

Search is made in vain for a corolla. This organ is in fact entirely wanting. When one set of the floral envelopes is lacking, it is usually, as in this case, the corolla. Such flowers, since they possess but one whorl of floral envelopes, are called *monochlamydeous.*

(2) *The Andrœcium.*—Counting the stamens, they are found to be twelve in number, but careful observation shows that six of them are shorter than the other six, and that they are inserted at a slightly lower level than, and alternate with, the remaining six. They are therefore to be regarded as occurring in two whorls of six stamens each. Each of the stamens has a color similar to that of the calyx, and each is provided with a short, thickish, outwardly-curved filament and a two-celled, adnate, and extrorse anther whose connective is conspicuously prolonged and pointed. The anthers dehisce longitudinally.

(3) *The Gynœcium.*—The pistil is provided with a short, thick, fleshy style that is crowned with a six-lobed stigma. Making a cross-section of the ovary, it is found to be distinctly six-celled, with several ovules in each cell. These ovules, it will be observed, are attached to the axis or central column of the ovary, so the placentation is denominated *axile* or axillary. Such a pistil is clearly six-carpeled, and in numerical plan corresponds, therefore, with the andrœcium. It may well be supposed to be made up as follows: the inturned edges of the carpellary leaves have grown toward the centre and met there, thus forming the partitions and central column and accounting for the axile placentation of the ovules, which are really borne on the infolded edges of the leaves, as has been observed in the Goldthread and Sweet Pea. If, in fact, study be made of the very young ovary of Asarum, it will be found to have six marginal placentæ, each with a double row of ovules on its edge. It is only later that these placentæ become prolonged so as to meet in the centre and form the axile placentation observed in the mature pistil. The law governing the structure of the compound pistil is thus the same as that governing the structure of the simple one.

(4) *Numerical Plan and Affinities.*—The peculiarities of structure thus far ascertained raise some questions as to the numerical plan and the affinities of the plant. Is the number plan three or six? The sepals, as has been observed, were three in number—or, rather, the calyx, being parted into three segments, indicates a construction on the numerical plan of three; but both stamens and pistils indicate a numerical plan of six. One might suppose the stamens to have been originally in four whorls of three each, which were afterward condensed into two of six each, and that a similar condensation took place in the case of the pistils. The numerical plan would then be that of three. But there is the alternative supposition that the calyx is the organ that has varied from the original plan, and that the numerical plan is to be regarded as that of six.

If the former supposition be accepted, is the plant a monocotyl or a dicotyl? Monocotyls, as has been noted, almost always have their flowers arranged on the numerical plan of three, while in dicotyls this plan is very rare. Observing the leaves, the venation is found to be netted; studying the stem, its vasal bundles are found arranged in a circle; there is a cambium zone, there are medullary rays and a pith,—facts all of which point to the affinities of the plant with dicotyls. If, further, the seed be dissected, there is found—though with difficulty, because it is minute—a dicotyledonous embryo, which is most conclusive proof that the plant is a dicotyl.

But the question remains, Is three or six the numerical plan of the flower? It seems, on the whole, more reasonable to conclude that six is the number, because this number is not rare among dicotyls, and because, moreover, it is more reasonable to suppose that one set of organs (the calyx) has deviated from the plan than that two sets (stamens and pistil) have done so.

Let the student now make a careful study and drawings of one of the other plants mentioned in the list at the beginning of this exercise.

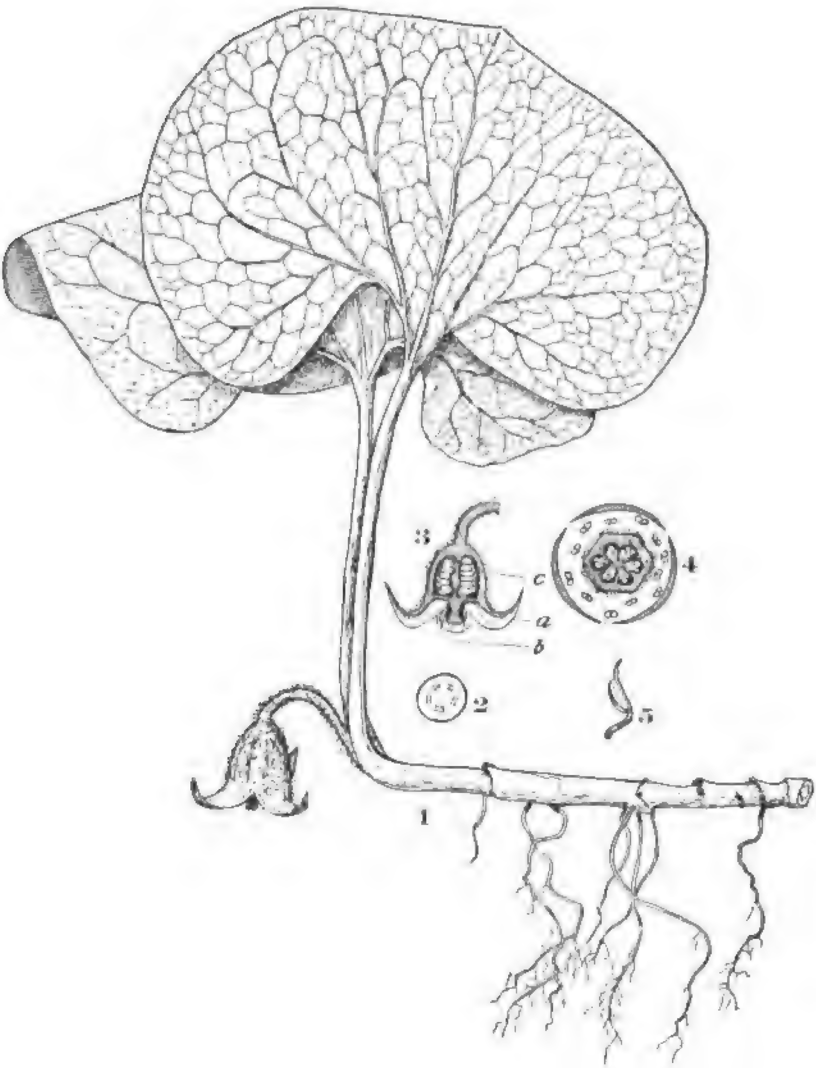


PLATE XXVI., FIG. 1.—Plant of Asarum canadense (¾ natural size), showing rhizome with its scale-scars and rootlets, the two large leaves, and the single, terminal, nodding flower.

FIG. 2.—Diagram of the Cross-section of the Stem, showing the interrupted circle of vasal bundles, the pith, and the thickish cortex.

FIG. 3.—Longitudinal section through the centre of the flower, the adherent calyx-tube, the epigynous arrangement of the stamens, etc.: *a* is one of the segments of the calyx; *b*, the stigma; and *c*, the ovary with its ovules.

FIG. 4.—Ground Plan of Flower.

FIG. 5.—One of the Stamens, showing adnate anther and prolonged connective.

EXERCISE XXIII.

STUDY OF A LILIACEOUS FLOWER: THE MONOCOTYL TYPE.

SELECTIONS may be made from the following common plants: the Tiger Lily (Lilium tigrinum, *Ker*), the Wild Orange Red Lily (Lilium Philadelphicum, *L.*), the Turk's-cap Lily (Lilium superbum, *L.*), the Indian Cucumber (Medeola Virginica, *L.*), the Large-flowered Trillium (Trillium grandiflorum, *Salisb.*), the Erect Trillium (Trillium erectum, *L.*), the American White Hellebore (Veratrum viride, *Ait.*), the Wild Onion (Allium cernuum, *Roth*), the Star of Bethlehem (Ornithogalum umbellatum, *L.*), the Wild Hyacinth (Camassia Frazeri, *Torr.*), the Bellwort (Uvularia perfoliata, *L.*), and the Yellow Adder's-tongue (Erythronium Americanum, *Ker*).

The last-named plant on this list shall serve the present purpose. The Yellow Adder's-tongue is a common plant in the northern and eastern portions of the United States and Canada, where it grows in rich woods, blossoming in early spring.

The underground parts consist of a deeply-buried tunicated bulb and numerous nearly simple, fibrous, adventitious roots which are emitted from its lower end. In the sterile plant this bulb usually sends up but a single leaf, but in the flowering one two apparently opposite, but really alternate, ones. These are each about four inches long, lanceolate, oblanceolate, or elliptic-lanceolate, entire, acute, thickish, with an indistinct basi-nerved venation, smooth and light-green, with darker green or purplish irregular spots on both surfaces. The leaves taper below into long petioles, the outer or lower of which ensheathes the next, and this in turn the long, naked, cylindrical scape. The latter rises to the height of five or six inches, and bears at its apex a single yellow, nodding flower.

(1) *The anthotaxy* is therefore solitary and determinate.

(2) *The prefloration*, if the perianth be studied carefully, is found to be valvate in the first whorl and imbricate in the second.

(3) *The perianth* is in fact composed of two whorls of three pieces each, the outer set representing the calyx and the inner one the corolla, for close inspection shows that the former differs from the latter slightly in size, shape, and depth of coloring, as well as in prefloration. The pieces are all distinct or not at all united with each other; the calyx and the corolla therefore are chorisepalous and choripetalous respectively. They are both inserted upon the receptacle beneath the pistil, and are therefore hypogynous. Each piece is lanceolate in form, and, when the flower is in full blossom, outwardly curved, or reflexed.

(4) *The andrœcium* consists of six distinct pieces also arranged in two whorls, the outer of these opposite the sepals and the inner opposite the petals. They are also hypogynous. Each stamen consists of a filament which is flattened below and narrowed to a slender point above, and an oblong, two-lobed and two-celled, introrse anther. The anther, being inserted by its base on the end of the filament, is said to be innate. It opens to shed the pollen by means of a slit running lengthwise of each cell, and the dehiscence is therefore said to be longitudinal. The pollen, it will be observed, is adhesive, and this, together with the showiness of the perianth, leads one to conclude that the flower is adapted to cross-fertilization by insect agency. That it must be, occasionally at least, fertilized by its own pollen is, however, sufficiently indicated by the fact that the stamens face inward and open in such close proximity to the stigmas, and by the fact that the latter are receptive simultaneously with the shedding of the pollen.

(5) *The gynœcium* consists of a single pistil which is complete in its parts, possessing an ovary, a style, and a stigma. The ovary is ellipsoidal or obovate in form, contracted into a short stalk at the base, and longitudinally three-lobed. The style is club-shaped, slender and somewhat bent below, and thick and obscurely three-lobed longitudinally in its upper portion. In height it attains about the same level as the top of the anthers. The stigma is terminal, and consists of a three-lobed papillose area at the apex of the style.

The ovules are numerous, horizontal, and anatropous, though the latter fact is not easily determined with an ordinary magnifying-glass.

Here is a single pistil where one would naturally expect three.

But even a superficial inspection shows that the single organ is probably formed by the coalescence of three, for the stigma, as has been seen, the upper part of the style, and the ovary are each three-lobed. Moreover, the lobes alternate with the inner set of stamens, as would be the case if the compound pistil were formed by the coalescence of three simple ones. But confirmatory evidence of the correctness of the view that the pistil is three-carpeled is obtained by studying the cross-section of the ovary. This section shows three loculi, each containing a double row of ovules arranged vertically along the inner side of the loculus —an axillary placentation, in fact, as in Asarum. This is the precise arrangement which would result if three carpellary leaves were folded inward until the edges touched at the centre and a row of ovules were borne on each infolded edge.

The flower, therefore, is really constructed throughout on the numerical plan of three; and, since there are five whorls of three each, all alternating with each other, it is wholly *symmetrical*. It is, in fact, a nearly typical or pattern flower, the only real deviation being a slight irregularity shown in the shape of the pistil. This is related to the nodding position of the flower, and both are doubtless adaptations to cross-fertilization by insect agency. In this flower the deviation is but slight. In many other monocotyls, as in some orchids, it has become extreme, so that there is not only great irregularity in the shape and coloring of parts, but great dissymmetry also, often obscuring even the numerical plan.

(6) *The Monocotyl Type of Flower.*—Except for its slight irregularity, the flower of the Adder's-tongue may be regarded as a flower typical of monocotyl plants, as the Flax and Sedum are of dicotyls. In all this vast group the flowers appear to have been constructed on the numerical plan of three and on the basis of five alternating whorls—one of sepals, one of petals, two of stamens, and one of pistils. In course of time many species have developed irregularities and dissymmetries, as has been seen among dicotyls, but seldom is the original plan completely obscured; and, since the flowers of dicotyls are rarely constructed on the numerical plan of three, the one group of plants may almost always easily be distinguished from the other by observing the numerical plan of the flowers.

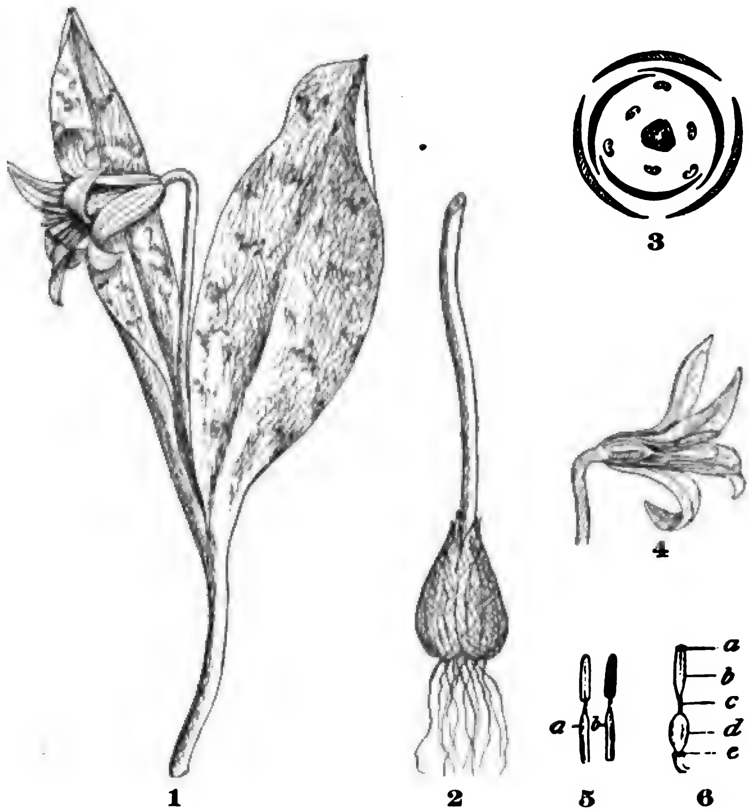


PLATE XXVII., FIGS. 1, 2.—Flowering Plant of Erythronium Americanum (⅔ natural size).

FIGS. 3, 4.—Ground Plan and Vertical Section respectively of the Flower.

FIG. 5.—One of the Stamens shown in dorsal (*a*) and in ventral (*b*) view.

FIG. 6.—Pistil: *a*, stigma; *b*, enlarged upper portion of style; *c*, contracted and somewhat bent lower part of style; *d*, ovary; *e*, torus.

EXERCISE XXIV.

FLOWERS OF MONOCOTYLS (CONTINUED).

IN connection with the study of a liliaceous flower, which has been taken as typical of the monocotyls, one may profitably study some of the flowers from related families in which the type has undergone modifications more or less important. Selections may be made from the Amaryllidaceæ and from the Orchidaceæ, as follows: *Amaryllidaceæ:* the Daffodil (Narcissus Pseudo-narcissus, *L.*), the Poet's Narcissus (Narcissus poeticus, *Salisb.*), the Jonquil (Narcissus Jonquilla, *Willd.*), the Polyanthus (Narcissus Tazetta, *Willd.*), or the Pancratium (Pancratium maritimum, *L.*). *Orchidaceæ:* the showy Orchis (Orchis spectabilis, *L.*), the Yellow Fringed Orchis (Habenaria ciliaris, *R. Br.*), the Fragrant Orchis (Habenaria leucophæa, *Gray*), the Arethusa (Arethusa bulbosa, *L.*), the Calopogon (Calopogon pulchellus, *R. Br.*), the Pogonia (Pogonia ophioglossoides, *Nutt.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Yellow Lady's Slipper (C. pubescens, *Willd.*), or the Stemless Lady's Slipper (C. acaule, *Ait.*).

PART I.—From these, for the first study, a selection is made of the commonly cultivated Narcissus poeticus. This is a spring-blooming plant with long, linear, parallel-veined, radical leaves which arise from a tunicated bulb. The flowers occur in a few-flowered umbel at the end of a scape, and the cluster is subtended at its base by a conspicuous, scale-like bract or spathe.

(1) *The perianth,* as in the Erythronium, is composed of six pieces, and these also are in two whorls of three each which alternate with each other, but the pieces have grown together at their base to form a long tube, so that the perianth is hypocrateriform. This growing together of parts, either of the same or of different whorls, constitutes one of the common ways in which many flowers have come to differ from the type. But the adhesion is car-

ried still farther in this instance. It will be observed that the perianth seems to spring from the top of the ovary instead of arising from the receptacle at its base. Unquestionably, in the remote ancestors of the plant it was hypogynous, as in Erythronium, but in course of time it has become adnate to the ovary, so as to seem to arise from its top, and is not therefore inappropriately described as epigynous.

(2) *The corona* constitutes another difference between this flower and that of Erythronium. This is a tubular or cup-shaped appendage arising from the throat of the perianth, and shown in section on Plate XXVIII. (Fig. 3, *a*). The real nature of this organ is not easily determined, and various theories, more or less plausible, have been advanced to account for it. By some the corona is regarded as consisting of two or more whorls of petals which have coalesced. As it is a not uncommon thing for the whorls of the corolla to be multiplied beyond the normal number, there is some reason in favor of the view, though, if this be its origin, it is difficult to understand why there should be such an abrupt transition from one kind of petaline whorl to another. If this were the case, one would expect to find in some members of the large Amaryllis family flowers in which there were forms transitional between the proper petals and the corona, but this is not the case. Others regard the corona as made up of staminodes, or abortive stamens, belonging to two or more whorls outside the regular ones. But there are the same objections to this as to the view just mentioned, the two whorls normally present in monocotyls being present here and being nearly normal in their dedelopment. Others still regard the corona as identical in its nature with the crown which is present in many flowers of the Pink family, where it undoubtedly represents the stipules of the coralline leaves. The fact that in some species of Narcissus the crown is more or less distinctly twelve-pointed, making two stipules for each leaf of the perianth, gives to this view much probability. Moreover, if the ligule of grasses be regarded as consisting of a pair of modified stipules, one may easily trace a close parallelism between it and the corona of this plant.

But still another view is that the corona is in the nature of a disk such as is present in the flower of the Orange, and which also occurs in many other plants, both dicotyls and monocotyls. This

disk is sometimes hypogynous as in the Orange, sometimes perigynous as in Buckthorn, and sometimes epigynous as in the Umbelliferæ. In the latter case it may rise considerably above the level of the ovary, and form a crown-like ridge or elevation as in Peliosanthes. The reasons for believing that the crown of Narcissus may be of this character, despite its membranous texture and petaloid appearance, are derived from a study of its development. It begins later than do the other floral organs, as a slight ring-like elevation between the staminal whorls and those of the andrœcium, and wholly independent of both. By its growth perianth and andrœcium are carried up together, forming the common tube which both envelops the ovary and is carried much beyond it, the crown, according to this view, being only the free portion of this remarkably developed disk. This is the view of M. Baillon, and as such must command great respect. But it seems to the author that the facts Baillon states regarding the development of the disk are not inconsistent with the view that the corona represents the coalesced stipules of the perianth leaves. The stipules, as well as the other parts, may have been carried up by the development of the disk. Their texture and the fact that they are sometimes twelve-toothed seem more in accord with this view.

But, after all, it is of less importance what view be adopted than that the process of reasoning by which the view is arrived at be understood.

(3) *The andrœcium* here, as in Erythronium, consists of two whorls of three stamens each, but, instead of being borne on the receptacle beneath the ovary, they have become adnate by their filaments to the perianth-tube, one set of anthers appearing near its throat and the other near the middle of the tube. The free portions of the filaments are very short, but they may be traced along the line of their attachment to the tube clear to the base of the latter. The anthers are two-lobed, two-celled, introrse, and attached to the filaments near their middle.

(4) *The gynœcium* in most respects resembles that of Erythronium except for the adnate perianth-tube and the slender, straight style, the ovary being three-lobed, three-celled, many-ovuled, and with an axile placentation.

The flower, like that of Erythronium, is also nearly regular, but shows, by being bent on its peduncle and by being somewhat

bent just above the ovary, so as to face laterally, a slight tendency toward irregularity.

In the Narcissus, then, may be seen a flower that in numerical plan and in the relative arrangement of its parts conforms to the monocotyl type, and deviates from the latter only in the development of a corona, in the growing together of its parts, and in the development of a slight irregularity.

PART II.—Now let there be compared with the structure of the flowers of Erythronium and Narcissus that of one of the Orchidaceæ, selecting for the purpose Cypripedium acaule. This plant, which is one of the commoner species of this curious genus, grows in low, sandy regions throughout the eastern and northern portions of the United States. From its small, contorted rhizome issue numerous tufted, simple, crinkled rootlets, twelve or fifteen centimetres long, and from its apex a flowering stem or scape which rises to the height of fifteen or twenty centimetres and bears leaves only at its base. These consist, first, of two or three scales, and then of two sheathing, simple, glandular-hairy foliage-leaves. The conspicuous purple flowers occur singly at the end of the scape, and each is subtended by a bract. The flowers are nodding, and the different floral organs are borne on the top of the ovary or are epigynous, as in Narcissus; but here the resemblance apparently ends, for the flower has become strangely unsymmetrical and irregular.

(1) *The sepals* are apparently but two in number, whereas one would expect three. If the lower sepal, however, be observed closely, there will be found indications in its venation of the coalescence of two, and sometimes further evidence of the same thing in the form of a slight notch at its apex. In some other species, as in Cypripedium pubescens, this notch is much more conspicuous, and in Cypripedium arietinum the three sepals are entirely distinct, as they are in Erythronium. The sepals, then, are really all present here, but the fact is obscured by the more or less complete coalescence of two of them.

(2) *The corolla* is much more profoundly changed. The two lateral petals are normally developed, though greenish in color, and are linear-lanceolate, somewhat twisted bodies, while the lower one, in the ordinary position of the flower, is an enormously

developed sac or moccasin-like body of a purple color, and totally different in appearance from the other two. This is called the *labellum.*

(3) *The column,* as it is called, is at its base a stout cylinder rising from the centre of the corolline whorl, and bearing on its upper side a thick, spade-shaped or somewhat rhomboidal body near the base of which, on either side, lie two gland-like bodies which, however, are really stamens. The spade-shaped body arches over a faintly and unequally three-lobed stigma which faces downward and terminates the column. In this organ, then, stamens and pistils have grown together or become adnate, and the arrangement is described as a *gynandrous* one.

(4) *The andrœcium* apparently consists of but the two gland-like stamens; but what has become of the other four? And do the two which are present belong to the inner or to the outer whorl? What is the nature of the spade-shaped body? Does it represent a petal or a stamen, or is it an outgrowth from the receptacle in the nature of a disk? These questions can be answered only by carefully studying the development of the flower, by comparing it with those of related plants, and by the study of those monstrosities which sometimes occur and indicate a return to an ancestral and more regular condition. It frequently happens both among animals and plants that an organ that has become rudimentary and tends to disappear suddenly appears fully developed; or that one which has become strongly irregular develops regularly; or that one which has disappeared entirely reappears. Thus, in some Scrophulariaceæ there is a rudimentary and functional fifth stamen which in rare instances develops into the ordinary form, or the petal of a Trillium or a Rose develops into an ordinary green leaf; and instances are on record where a Cypripedium has developed a perianth perfectly regular and symmetrical; and at least one instance of the kind is recorded where all the stamens but one have been restored and in their normal positions. From the study of such instances it may be concluded that the spade-shaped body of this flower is actually one of the outer whorl of stamens and really represents the hypertrophied connective of one of the anthers, and that the other two stamens belong to the second or inner whorl, the third having disappeared or perhaps coalesced with the lower petal to form the labellum.

(5) *The Gynœcium.*—This also has become strongly altered from that of the monocotyl type, but the type is still recognizable through the modifications. The ovary shows exteriorly a three-lobed character; the stigma, though irregular, is three-lobed; and a cross-section of the ovary shows three marginal placentæ,—all indicating that the pistil is composed of three united carpels. Besides the irregular stigma, the bent style, and the curved ovary, there is another irregularity which merits attention—namely, the twist in the ovary. Close observation shows that it is twisted through half a revolution, thus inverting the flower. The labellum, therefore, which appears to be the lower petal, is really the upper one; and, similarly, the spade-shaped body represents the lower stamen of the outer whorl, instead of the upper one.

(6) *The ground plan* of the flower, therefore, is as represented in Figure 2 (Pl. XXIX.), the dot indicating which is the real upper side of the flower, and the organs with dotted outlines representing the floral parts that have disappeared.

(7) *The Pollination.*—The explanation for these strange irregularities and dissymmetries is that the flower has become gradually modified in relation to its insect visitors. The mode of cross-fertilization in this flower affords an interesting study, and the process is briefly outlined as follows: The insect, usually a bee or a wasp, pushes its way through the closed slit in the labellum at *e*, and, once inside, proceeds to the base, where is secreted the nectar, the object of the visit; in doing this the insect necessarily passes under and rubs against the stigma, any pollen which may have adhered to the back of the insect from a visit to another flower being deposited upon the stigma; having sipped the nectar, the insect emerges from the labellum, not by retracing the path pursued in entering, but, seeing light under the spade-shaped body at *c*, by forcing a way out there; in so doing the insect rubs its back against one of the two anthers, and carries the pollen away to the next flower visited.

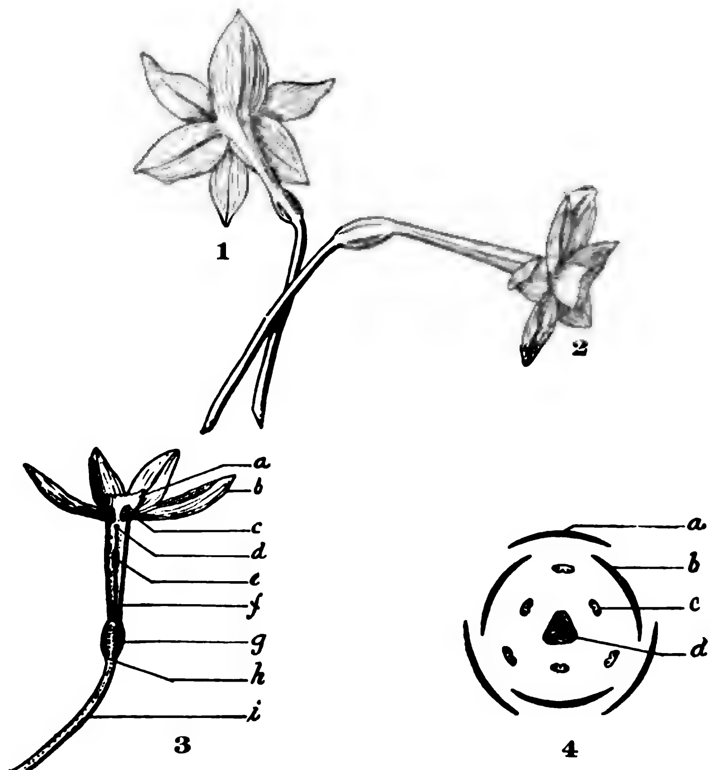


PLATE XXVIII., FIGS. 1, 2.—Flowers of Narcissus poeticus in different positions ($\frac{3}{5}$ natural size).

FIG. 3.—Vertical Section of one of the Flowers, showing, *a*, corona; *b*, one of the petals; *c*, one of the stamens; *d*, the stigma; *e*, an anther; *f*, the style; *g*, the ovary; *h*, the receptacle; and *i*, the peduncle.

FIG. 4.—Ground Plan of Narcissus Flower: *a*, sepal; *b*, petal; *c*, stamen; *d*, ovary.

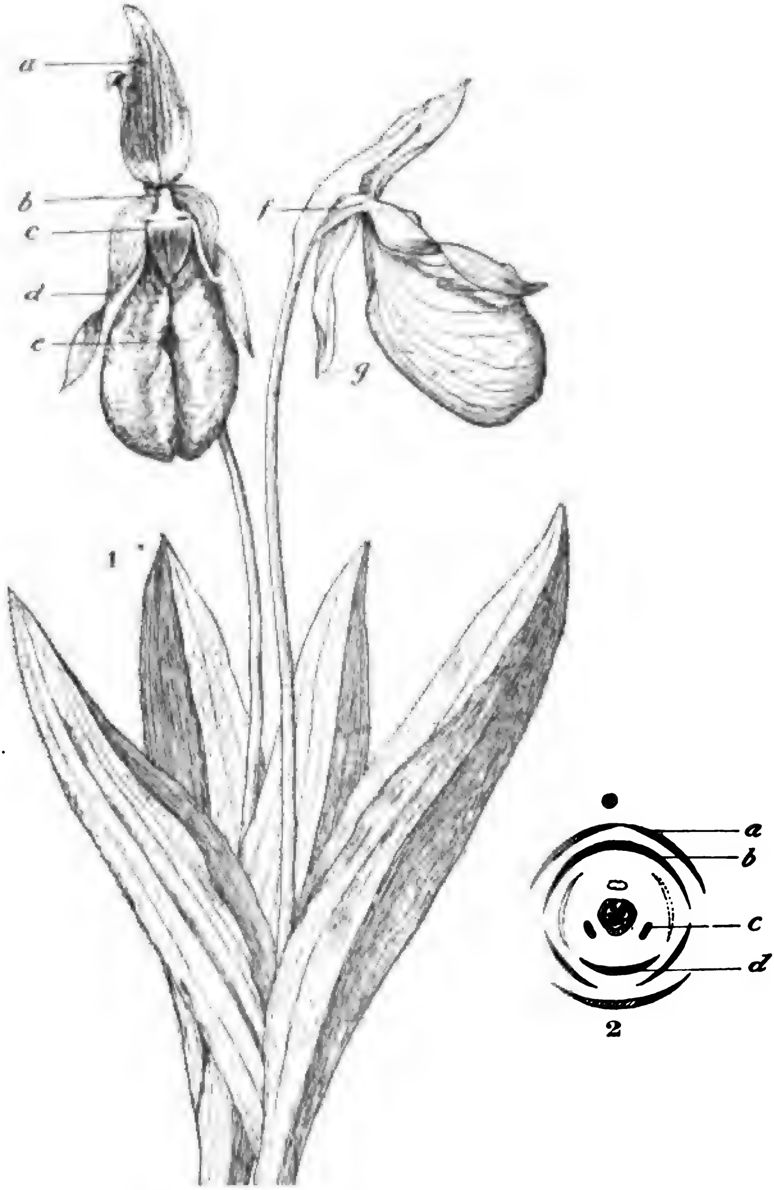


PLATE XXIX., FIG. 1.—Two Plants of Cypripedium acaule (⅔ natural size), showing flowers in different positions: *a*, sepal; *b*, base of column; *c*, opening from which insect emerges; *d*, lateral petal; *e*, slit through which insect enters; *f*, ovary; *g*, upper two sepals united into one.

FIG. 2.—Ground Plan of one of the Flowers: *a*, upper two sepals united into one; *b*, labellum; *c*, a stamen; *d*, spade-shaped body, an abortive stamen.

EXERCISE XXV.

STUDY OF THE INFLORESCENCE OF AN ABERRANT MONOCOTYL, ONE OF THE ARACEÆ.

THE following are species most of which are not difficult to procure in the proper season, and which are suitable for study: the Indian Turnip (Arisæma triphyllum, *Torr.*), the Green Dragon (Arisæma Dracontium, *Schott.*), the Arrow Arum (Peltandra Virginica, *Kunth*), the Water Arum or Calla (Calla palustris, *L.*), the Calla Lily (Richardia Æthiopica, *Kunth*), the Golden Club (Orontium aquaticum, *L.*), the Skunk Cabbage (Symplocarpus fœtidus, *Salisb.*), and the Sweet Flag (Acorus Calamus, *L.*).

For the purposes of this exercise selection is made of the first on the list, the Indian Turnip. The plant is very common in low, rich woods throughout the eastern portion of the United States and Canada, where it blossoms in early spring. It has a flattened, much wrinkled corm that may attain a transverse diameter of two inches and a vertical diameter half as great, and emits numerous nearly simple, adventitious roots from its upper margin. From near the centre of its upper surface rises, to the height of six inches or even a foot or more, the erect, rather stout, cylindrical scape. The lower part is enveloped in alternate sheathing scales and the sheathing base of the true leaf or leaves. The scales are large, particularly the upper ones, and conspicuously parallel-nerved. The true leaves, one or two in number, like the scales, have their origin in the corm. Besides the long sheath, which completely surrounds the flower-stem, the leaf consists of a rather long, cylindrical petiole and a ternately-divided blade. The leaf deviates in structure from that of the great majority of monocotyls in being reticulate instead of nerved. The segments are ovate, entire-margined, acuminate, and have a sub-marginal vein running from the base to the apex. The whole plant is smooth, and the watery juice is very acrid.

(1) *The anthotaxy* is of that variety of the indeterminate type which is called the *spadix;* that is, the florets of the cluster are sessile and arranged along a fleshy, usually elongated axis which is subtended by a conspicuous and often showy bract called the spathe. In this instance the lower part of the spadix, which is conical in form, is the only flower-bearing part. The upper portion is elongated, smooth, and club-shaped. The lower part of the spathe is rolled into an ob-conical or nearly cylindrical tube which nearly encloses the spadix, and the upper part is flattened, ovate-lanceolate, and acuminate, and arches over the top of the spadix. It is more or less ornamented with purplish blotches.

(2) *The flowers* are of two kinds, staminate and pistillate, sometimes both borne on the same spadix (monœcious), the staminate above the pistillate, and sometimes on the spadices of different plants of the species (diœcious). The floral envelopes are wholly wanting.

(*a*) *The staminate flowers* consist each of a single stamen with a very short and stout filament and a four-celled anther, each cell opening above by a narrow chink or pore. The pollen-grains are spherical and studded with minute points.

(*b*) *The pistillate flowers* are equally simple, consisting each of a single pistil. This has at its apex a small sessile stigma. The ovary is rounded or faintly triangular, one-celled, and usually about six-ovuled. Each fertilized pistil becomes, when ripe, a scarlet berry.

The characters of the plant, it will be observed, are somewhat contradictory. If a cross-section of the corm or of the scape be made, the vasal bundles will be found scattered as in monocotyls, while the leaves have the netted venation of dicotyls and the flowers are so reduced that from these alone it would be impossible to decide to which of the two groups the plant belongs. But much light may be derived from the comparison of this with related plants. In the Calla Lily, for example, the pistil is distinctly three-carpeled, as shown on Plate XXX. (Fig. 4, *a* and *b*). This and other facts derived from the study of manifestly related plants lead to the conclusion that the one-celled pistil of Arisæma is really three-carpeled, though the fusion is so complete that the traces of its compound character have nearly disappeared.

In some other members of the order, as in Orontium, there is

a perianth of six pieces, as in most monocotyls; so there can be no doubt that Arisæma is really a monocotyl, though by the reduction of its parts it has become very aberrant from its type. This instance illustrates the value of comparison in determining the relationships of a species.

Another thing that should be learned from the study of this plant is that hard and fast lines cannot be drawn even between two groups usually so distinct as monocotyls and dicotyls, much less between smaller and more nearly related groups. Nearly always dicotyls have net-veined leaves and monocotyls nerved ones, but here is a monocotyl whose leaves possess the net-veined character of dicotyls. It is in some respects on the border-line—a connecting-link—between two great sub-classes. Connecting-links between species, genera, and even orders, are, contrary to the popular supposition, far from being rare in the vegetable kingdom.

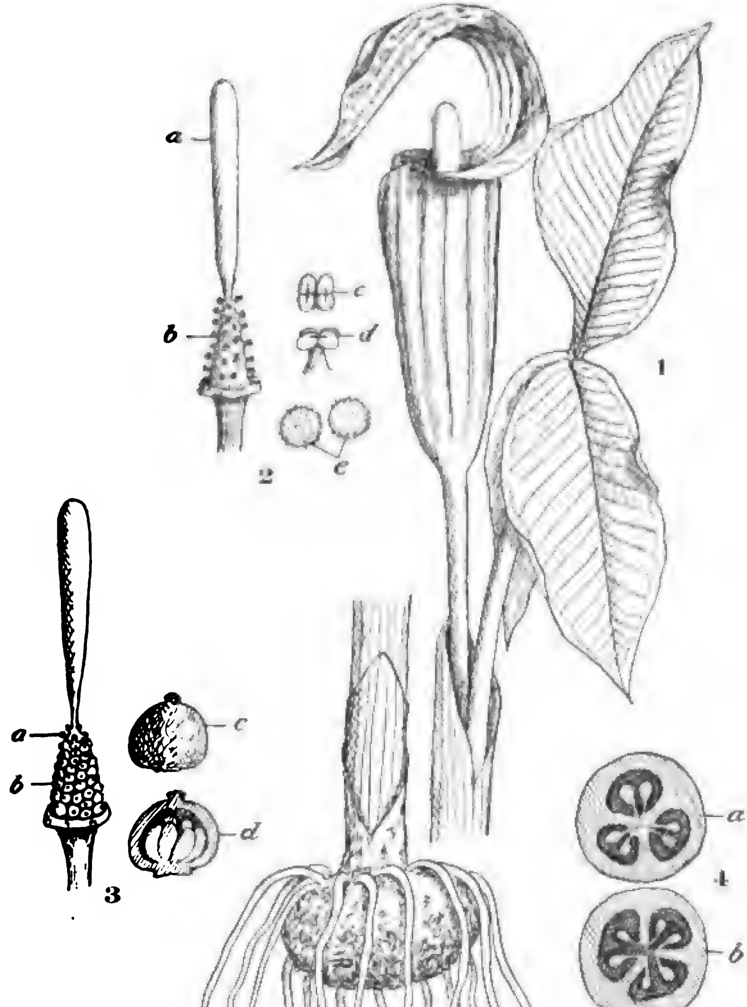


PLATE XXX., FIG. 1.—Plant of Arisæma triphyllum (about ⅞ natural size).

FIG. 2.—Staminate spadix with spathe cut away to show the flowers: *a*, naked portion of spadix; *b*, a staminate flower; *c*, an enlarged view of upper side of a stamen; *d*, a lateral view of the same; *e*, two pollen-grains strongly magnified.

FIG. 3.—Spadix of another flower of the same species in which only a few staminate flowers are present, but numerous pistillate ones: *a*, staminate flower; *b*, pistillate flower; *c*, one of the pistils enlarged; *d*, the same in longitudinal section, showing the six orthotropous ovules arising from a basal placenta.

FIG. 4.—Sections of Ovary of Calla Lily: *a*, of lower part, where three placentæ meet in the centre; and *b*, of the upper part, where the placentation is marginal.

FORM FOR THE STUDY OF FLOWERS.

I. ANTHOTAXY.

1. *Indeterminate.*
   (1) Solitary.
   (2) Raceme.
   (3) Compound raceme or panicle.
   (4) Corymb.
   (5) Compound corymb.
   (6) Umbel.
   (7) Compound umbel.
   (8) Spike.
   (9) Compound spike.
   (10) Head.
   (11) Spadix.
   (12) Catkin.
2. *Determinate.*
   (1) Solitary.
   (2) Cyme.
   (3) Compound cyme.
   (4) Fascicle.
   (5) Glomerule.
   (6) Scorpioid cyme.
   (7) Helicoid cyme.
   (8) Verticillaster.
3. *Mixed.*
   (1) Mixed panicle.
   (2) Thyrsus.
   (3) Spiked verticillaster.
   (4) Cymed heads.
   (5) Corymbed cymes.

II. PREFLORATION.

1. *Individual piece.*
   (1) Not bent or folded.
   (2) Inflexed.
   (3) Reflexed.
   (4) Conduplicate.
   (5) Convolute.
   (6) Circinate.
   (7) Plicate.
   (8) Involute.
   (9) Revolute.
2. *Relative position of pieces.*
   (1) Valvate series.
      a. Valvate.
      b. Induplicate-valvate.
      c. Reduplicate-valvate.
      d. Involute-valvate.
      e. Revolute-valvate.
   (2) Imbricate series.
      a. Imbricate.
      b. Quincuncial.
      c. Vexillary.
      d. Equitant.
      e. Half-equitant.
      f. Triquetrous.
3. *Gamophyllous organs.*
   (1) Contorted.
   (2) Plicate.
   (3) Supervolute.

III. KINDS OF ORGANS PRESENT.

1. Bracts.
2. Bracteoles.
3. Involucre.
4. Involucel.
5. Epicalyx.
6. Torus.
7. Calyx.
8. Corolla.
9. Nectaries.
10. Stamens.
11. Staminodes.
12. Pistils.

IV. NUMERICAL PLAN.

1. Monomerous.
2. Dimerous.
3. Trimerous.
4. Tetramerous.
5. Pentamerous.
6. Hexamerous.
7. Heptamerous.
8. Octamerous.
9. Polymerous.

V. SYMMETRY.

1. Symmetrical.
2. Unsymmetrical calyx.
3. " corolla.
4. " stamens.
5. " pistils.

VI. REGULARITY.

1. Regular.
2. Irregular calyx.
3. " corolla.
4. " stamens.

VII. FERTILIZATION.

1. *Autogamous.*
2. *Cleistogamous.*
3. *Allogamous.*
   (1) Anemophilous.
      a. Monœcious.
      b. Diœcious.
      c. Hermaphrodite.
         (*a*) Protandrous.
         (*b*) Protogynous.
   (2) Entomophilous.
      a. Monœcious.
      b. Diœcious.
      c. Hermaphrodite.
         (*a*) Protandrous.
         (*b*) Protogynous.
         (*c*) Dimorphous.
         (*d*) Trimorphous.
         (*e*) Irregularity.
         (*f*) Special adaptations.

VIII. BRACTS.

1. Herbaceous.
2. Scarious.
3. Petaloid.
4. Deciduous.
5. Persistent.

IX. INVOLUCRE.

1. Herbaceous.
2. Scarious.
3. Sacrious-tipped.
4. Scarious-margined.
5. One-rowed.
6. Two-rowed.
7. Imbricated in several rows.

X. TORUS.

1. Flat.
2. Convex.
3. Hemispherical.
4. Conical.
5. Concave.
6. Hollow.

XI. CALYX.

1. *Insertion.*
   (1) Hypogynous.
   (2) Perigynous.
   (3) Epigynous.
2. *Chorisepalous.*
   (1) Sepals:
      Sessile.
      Unguiculate.
      Calcarate.
      Filiform.
      Linear.
      Oblong.
      Clavate.
      Elliptical.
      Lanceolate.
      Oblanceolate.
      Ovate.
      Obovate.
      Orbicular.
      Emarginate.
      Cordate.
      Obcordate.
      Saccate.
      Entire.
      Toothed.
      Fringed.
      Herbaceous.
      Scarious.
      Petaloid.
      Length.
3. *Gamosepalous.*
   (1) Tubular.
   (2) Rotate.
   (3) Campanulate.
   (4) Infundibuliform.
   (5) Hypocrateriform.
   (6) Urceolate.
   (7) Globose.
   (8) Inflated.

(9) Bilabiate.
(10) Saccate.
(11) Calcarate.
(12) Herbaceous.
(13) Petaloid.
(14) Length of tube.
(15) Limb.
a. Entire.
b. Toothed.
c. Fringed.
d. Crisped.
e. Lobed.
f. Parted.
g. Divided.
(16) Number of component sepals.

4. *Duration.*
(1) Caducous.
(2) Deciduous.
(3) Withering.
(4) Persistent.
(5) Accrescent.

XII. COROLLA.

1. *Insertion.*
(1) Hypogynous.
(2) Perigynous.
(3) Epigynous.

2. *Choripetalous.*
(1) Petals:
Sessile.
Unguiculate.
Coronate.
Calcarate.
Filiform.
Clavate.
Linear.
Oblong.
Elliptical.
Lanceolate.
Oblanceolate.
Ovate.
Obovate.
Orbicular.
Emarginate.
Obcordate.
Cordate.
Entire.
Toothed.
Fringed.
Color.
Length.
Number.

3. *Gamopetalous.*
(1) Tubular.
(2) Rotate.
(3) Campanulate.
(4) Infundibuliform.
(5) Hypocrateriform.
(6) Urceolate.
(7) Globose.
(8) Inflated.
(9) Bilabiate.
(10) Personate.
(11) Ringent.
(12) Ligulate.
(13) Saccate.
(14) Calcarate.
(15) Coronate.
(16) Length of tube.
(17) Limb.
a. Entire.
b. Toothed.
c. Fringed.
d. Crispate.
e. Lobed.
f. Parted.
g. Divided.
(18) Color.
(19) Number of component petals.

4. *Duration.*
(1) Caducous.
(2) Deciduous.
(3) Withering.
(4) Persistent.

XIII. ANDRŒCIUM.

1. *Number of stamens.*
(1) Monandrous.
(2) Diandrous.
(3) Triandrous.
(4) Tetrandrous.
(5) Pentandrous.
(6) Hexandrous.
(7) Heptandrous.
(8) Octandrous.
(9) Enneandrous.
(10) Decandrous.
(11) Endodecandrous.
(12) Duodecandrous.
(13) Polyandrous.

2. *Grouping of stamens.*
(1) Distinct.
(2) Monadelphous.
(3) Diadelphous.
(4) Triadelphous.
(5) Polyadelphous.
(6) Syngenesious.
(7) Didynamous.
(8) Tetradynamous.

3. *Insertion of stamens.*
(1) Hypogynous.
(2) Perigynous.
(3) Epigynous.
(4) Epipetalous.
(5) Gynandrous.
(6) Included.
(7) Protruding.
(8) Equal in length.
(9) Unequal in length.

4. *Parts.*
(1) Filament.
a. Wanting.
b. Filiform.
c. Awl-shaped.
d. Clavate.
e. Bearded.
f. Appendaged.
g. Petaloid.
(2) Anthers.
a. Insertion.
(*a*) Sessile.
(*b*) Introrse.
(*c*) Extrorse.
(*d*) Adnate.
(*e*) Innate.
(*f*) Versatile.
b. Dehiscence.
(*a*) Longitudinal.
(*b*) Transverse.
(*c*) Valvular.
(*d*) Porous.
(*e*) Irregular.
c. Structure.
(*a*) Unilocular.
(*b*) Bilocular.
(*c*) Quadrilocular.
(*d*) Dimidiate.
(*e*) Appendaged.
d. Connective.
(*a*) Narrow.
(*b*) Broad.
(*c*) Caudate.
(3) Pollen.
a. Powdery.
b. Adhesive.
c. In masses or pollinia.

XIV. GYNŒCIUM.

1. *Kind.*
(1) Gymnospermous.
(2) Angiospermous.
(3) Apocarpous.
(4) Syncarpous.

2. *Apocarpous gynœcium.*
(1) Number of carpels.

3. *Syncarpous gynœcium.*
(1) Number of component carpels.
(2) Degrees of union.
a. Ovaries partly united.
b. Ovaries wholly united.
c. Ovaries and part of styles united.
d. Ovaries and styles united.
e. Stigmas only united.

4. *Parts.*
1. Ovary.
2. Style.
3. Stigma.

EXERCISE XXVI.

STUDY OF FRUITS: SOME APOCARPOUS FRUITS.

SELECTIONS may be made from fruits of the following plants: the Buttercup (Ranunculus bulbosus, *L.*), the Marsh Marigold (Caltha palustris, *L.*), the Goldthread (Coptis trifolia, *Salisb.*), the Moonseed (Menispermum Canadense, *L.*), the Common Pea (Pisum sativum, *L.*), the Scarlet Runner (Phaseolus multiflorus, *Willd.*), the Cultivated Cherry (Prunus avium, *L.*), the Peach (Prunus Persica, *L.*), the Common Plum (Prunus domestica, *L.*), and the Common Milkweed (Asclepias cornuti, *Decaisne*).

From these are taken for the present purpose two which differ from each other quite widely—the fruit of the Common Pea and that of the Cultivated Cherry.

A fruit may be defined as a ripened pistil. It is nothing more, in most cases, than a hollow vessel or pericarp containing in its interior a seed or seeds. This ripened pistil, like that of the immature one in the flower from which it is derived, may represent a single leaf or a cluster of united leaves; that is, it may be either *apocarpous* or *syncarpous*. It usually follows the structure of the pistil also in its placentation and in the number of its loculi, though rarely both undergo changes in development. The texture of the pericarp shows great variety in its structure in different fruits: it is sometimes thick and sometimes thin; sometimes hard and sometimes soft; sometimes hard exteriorly and soft interiorly, and sometimes the reverse; sometimes smooth exteriorly and sometimes roughened, hairy, spinose, alate, or papillose; and sometimes dehiscent and sometimes indehiscent. Most of the different forms the pericarp assumes have reference in some way to the modes of dispersion—by the wind, by animals, or by some other agency.

But fruits are often something more than single ripened pistils: they may consist of a cluster of distinct pistils which still remain

attached to the common receptacle, as in the Blackberry, Anemone, and Mulberry, and these clusters may be the product of a single flower, as in the first two examples mentioned, or the product of a flower-cluster, as in the last and in the Pineapple. In the former case they are called *aggregated* fruits, in the latter *multiple* ones. Moreover, in another way a fruit is not always simply a ripened pistil. Take the Strawberry as an example. Here the fruits proper are the small, seed-like bodies (achenia) sprinkled over the conical, fleshy, scarlet pulp, which is really the greatly enlarged receptacle. The whole is called a fruit; it is an aggregated fruit with an accessory receptacle. So also there are fruits in which the persistent calyx constitutes a conspicuous part, or fruits with an accessory calyx.

With this preface, let us proceed to the study of—

I. THE FRUIT OF THE PEA.—This fruit is commonly called a pod, and in cookery it is treated as a vegetable, but in the botanical sense it is as much a fruit as is an apple or a grape. In making a study of it, it would be well to have before the student both ripe and fully-grown but unripe pods.

(1) *External Characteristics.*—Distinction must first be made between the base and the apex of the fruit. At the former there will be found, when the fruit is ripe, the withered remains of the calyx. It is therefore a *superior* fruit. At the apex will be seen the withered base or scar of the style, which, having performed its functions in the flower, has partially or wholly disappeared along with the stigma. In some kinds of fruits both persist and constitute a part of the ripe fruit.

The pericarp of the ripe Pea fruit is dry, rather thin—that is, of about the thickness of cardboard—and rather hard and elastic. If it has not yet dehisced, there may be observed on opposite edges, and running from base to apex, two sutures—one, usually that on the straighter edge, called the *ventral*, and the other the *dorsal* suture. When the pod is fully ripe slight pressure will cause its dehiscence along these sutures, and at the same time the two valves become somewhat twisted. These movements are the result of unequal drying, which produces a strain upon the pericarp, and it needs only a touch or a slight blow to cause the structure to yield along its weaker portions, which in this case are the sutures. As a result of the dehiscence the seeds are usually thrown

out, not merely dropped out. Dispersion of the species is thus facilitated.

(2) *Internal Structure.*—Selecting a fruit which is fully grown, but not yet ripe, it is opened carefully along its sutures. The seeds will be found arranged as shown on Plate XXXI. (Fig. 2). They are borne along one suture—the ventral—but not along the other. Moreover, the seeds are attached alternately, first on one edge and then on the other. In fact, these edges are the infolded margins of the carpellary leaf, the other suture representing the midrib of the leaf. The placentation is *marginal* and the fruit is *apocarpous*. A dry apocarpous fruit which dehisces into two valves along its dorsal and ventral sutures is technically called a *legume*. Fruits of this type are common in the Pulse family of plants, hence the name Leguminosæ.

II. THE FRUIT OF THE CHERRY.—This fruit usually has the form of an oblate spheroid with a slight concavity at the basal end into which the end of the peduncle fits, and sometimes a shallow groove running from base to apex along one side. In this, as in the example just studied, one sees by observing the base that the calyx forms no part of the fruit, which is therefore *superior*. At the apex is found a minute scar marking the position of the style, which here also has withered and disappeared.

(1) *The pericarp* is altogether different in its texture from that of the Pea, and it does not dehisce when ripe. It has, in fact, in its development from the pistil become differentiated into two portions widely unlike in texture: the outer, called the *sarcocarp*, is thick and juicy, constituting the edible part of the fruit, while the inner part, called the pit or *putamen*, is developed into a hard, bony enclosure for the seed.

(2) *Evidence that the Fruit is Apocarpous.*—Owing to the great thickening of the pericarp and the succulency of its outer part, it is more difficult to demonstrate from the study of the fruit alone that it is composed of a single modified leaf than it is in the case of the Pea, for the dorsal and ventral sutures are seldom distinctly traceable from the outside. The shallow groove often seen on the outside, running lengthwise of the fruit, is, however, significant. It is really the ventral suture. Sometimes, though rarely, the dorsal suture is traceable as a faint ridge on the opposite side. The one-carpeled character, however, is evident if the

pistil of the flower be studied. Moreover, the sutures, both dorsal and ventral, are more or less distinctly traceable as ridges on the pit, running from base to apex on opposite sides.

(3) *Internal Structure.*—If the pit be divided transversely, there will usually be found but a single seed; but if a similar section of the ovary of the flower be made, there will be found two ovules, these being attached side by side, adjacent to the ventral suture, as in the Pea. In fact, in rare instances both ovules develop and the pit is then two-seeded.

A fruit of this type—an indehiscent fruit whose pericarp is differentiated into sarcocarp and hard endocarp—is technically called a *drupe.* This sort of fruit may be one-carpeled, as in the present instance, or it may be two- or more carpeled.

The question naturally arises, Why should two pistils constructed on the same essential plan develop into fruits so widely different in appearance and structure as those of the Pea and the Cherry? The question can partially be answered by supposing them to be adapted in different ways to dispersion. The seeds of the Pea, though edible, are not protected from animal enemies, and for this reason, perhaps, are produced in greater numbers in the fruit. A sufficient number of the seeds scattered by the dehiscence of the pods will usually elude the observation of animals to serve the purpose of reproduction.

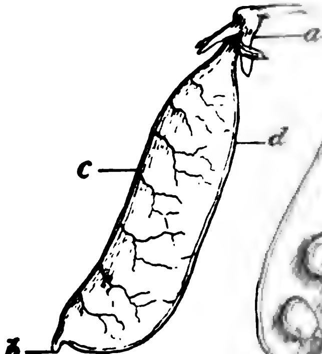
The sarcocarp of the Cherry was manifestly fitted to be eaten; it has an attractive color and a pleasant taste, but the seed at the same time is protected from destruction by its bony enclosure. Most of the smaller animals will reject the pit, but in devouring the rest they are liable to convey the protected seed to a distance from the parent tree. Some few seeds, at least, will probably be left in positions favorable for germination and growth into trees. None the less is the dispersion of the species promoted if the fruits are devoured whole by larger animals, for the bony pit in this case will usually protect the seed from digestion; it will, in fact, often pass through the alimentary canal only the better prepared for germination. There is every reason for believing that the qualities which render the Cherry, the Peach, the Plum, and other similar fruits desirable for food have been gradually developed in the course of ages by the selection exercised by frugivorous animals. All species vary more or less, and those varieties whose fruits were

most easily seen by animals and most palatable to them, and at the same time possessed the most thoroughly protected seeds, would be most likely to survive in the struggle for existence and to perpetuate their kind. So, in course of time, thick-walled, luscious, and relatively large and showy fruits have been developed from forms that, from the standpoint of the modern epicure, would be wholly undesirable. Animals, in fact, have been doing blindly what the horticulturist in recent times has been accomplishing with greater intelligence and more rapidity.

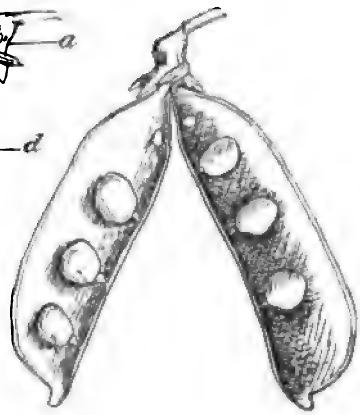
(4) *The seed* in the Cherry is so large that its structure may easily be determined with the simple microscope. In the first place, it will be observed that the seed is *pendulous*, or points obliquely downward toward the base of the fruit; it is also *anatropous*, having a raphé running nearly the whole length of one edge, and the hilum and micropyle located adjacent to each other at the end opposite the chalaza.

Removing the thin coats, it will be seen that the whole interior consists of embryo. The seed is without a food-supply not a part of the embryo, or, as the botanist expresses it, is *exalbuminous*. The embryo is also straight and has two large, fleshy cotyledons with convex exterior faces and flat interior ones, a small caulicle tipped with a minute radicle, and between the bases of the cotyledons a minute plumule. It is, in fact, a quite typical dicotyledonous embryo.

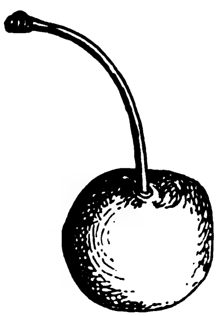
If the structure of one of the seeds taken from the pea-pod be compared with the seed just observed, there will be found a close resemblance in all essential respects. Both seeds are exalbuminous, both are anatropous, both are dicotyledonous, and both have embryos with excessively thickened cotyledons. The most conspicuous difference is the fact that in the Pea the embryo is not straight, but the caulicle is bent up against the edges of the cotyledons.



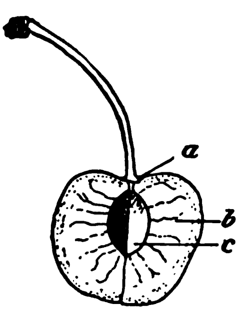
1



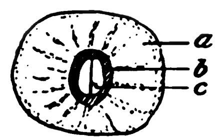
2



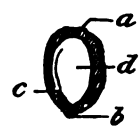
3



4



5



6

PLATE XXXI., FIG. 1.—Fruit of Pea: *a*, withered calyx at base of fruit; *b*, relic of style; *c*, ventral suture; *d*, dorsal suture.

FIG. 2.—Young Fruit opened to show placentation.

(Both figures about ⅔ natural size.)

FIG. 3.—Fruit of Cherry (about ⅔ natural size).

FIG. 4.—The same in Vertical Section through Sarcocarp: *a*, concave base, showing attachment to peduncle and scar of calyx; *b*, sarcocarp; *c*, endocarp or putamen.

FIG. 5.—Transverse Section through the middle of the Fruit: *a*, sarcocarp; *b*, endocarp; *c*, one of the cotyledons of the embryo.

FIG. 6.—The Putamen (somewhat enlarged): *a*, the basal end; *b*, the apex; *c*, hilum of seed; and *d*, the embryo.

EXERCISE XXVII.

STUDY OF FRUITS: SOME SYNCARPOUS FRUITS.

THE following are dehiscent kinds of fruits, of common occurrence, from which studies may be made: the Opium Poppy (Papaver somniferum, *L.*), the Celandine (Chelidonium majus, *L.*), the Black Mustard (Brassica nigra, *Koch*), the Common Blue Violet (Viola palmata, *L.*), the Corn Cockle (Lychnis Githago, *Lam.*), the Shrubby Mallow (Hibiscus Syriacus, *L.*), the Coriander (Coriandrum sativum, *Willd.*), the Cranesbill (Geranium maculatum, *L.*), the Jewel Weed (Impatiens fulva, *Nutt.*), the Evening Primrose (Œnothera biennis, *L.*), the Stramonium (Datura Stramonium, *L.*), the Henbane (Hyoscyamus niger, *L.*), the Tulip (Tulipa Gesneriana, *Willd.*), the Blue Flag (Iris versicolor, *L.*), the Stemless Lady's Slipper (Cypripedium acaule, *Ait.*), and the Colchicum (Colchicum autumnale, *L.*).

The following plants afford easily obtainable indehiscent kinds: the Common Apple (Pyrus Malus, *L.*), the Pear (Pyrus communis, *L.*), the Crab-apple (Pyrus coronaria, *L.*), the Service Berry (Amelanchier Canadensis, *Torr.* and *Gray*), the Gooseberry (Ribes cynosbati, *L.*), the Orange (Citrus Aurantium, *Willd.*), the Lemon (Citrus Limonum, *Risso*), the Cucumber (Cucumis sativus, *L.*), the Potato Berry (Solanum tuberosum, *L.*), the Ground Cherry (Physalis pubescens, *L.*), and the Birthwort (Trillium erectum, *L.*).

For the first part of this exercise the fruits of the Poppy, the Colchicum, and the Henbane will be studied, and they will be taken up in the order named.

I. FRUIT OF THE POPPY.—(1) *External Characteristics.*—The Common or Opium Poppy is widely cultivated for ornament and, in certain portions of the world, as the source of the important drug opium. The fruits vary much in size in the different varieties, sometimes attaining a length of three inches or more, but averaging, perhaps, a length of an inch and a half to

two inches. The fruits are dry when ripe, oblong or globular, more or less ribbed longitudinally, and crowned by a star-shaped, many-rayed, nearly sessile stigma. They are somewhat stalked at the base, and on the receptacle from which this stalk rises may be observed the scars of the floral organs that have fallen away—sepals, petals, and stamens. The number of ribs and the corresponding number of rays to the stigma are outside indications which point to the conclusion that the fruit is syncarpous and made up of a considerable number of carpels. Further indications are the little pores or valves of dehiscence which may be seen underneath the margins of the stigma, which correspond in number with the rays of the stigma and with the ribs of the ovary, and from which the seeds escape.

(2) *The internal structure*, as seen in cross-section, confirms this conclusion. Corresponding in number to the ribs and stigmatic lines are marginal placentæ projecting well into the cavity of the fruit. On these placentæ are borne, in double series, the very numerous and minute seeds. In the fruit shown in the illustration (Pl. XXXII. Fig. 2) there are fourteen placentæ, and therefore fourteen carpels, but the number will be found to vary in different fruits of the species.

(3) *The dehiscence*, as has been observed, is by valves underneath the stigmas. It will be well, in order to understand the nature of the dehiscence, to compare the different kinds that occur in capsules, for a syncarpous, dry, dehiscent fruit is termed a *capsule.*

If a capsule is composed of leaf-elements or carpels united by their edges, it would naturally be expected that when dehiscence takes place to scatter the ripe seeds, this dehiscence would occur by the separation of the carpels along the line of their original junction. This is, in fact, most commonly the case, and dehiscence of this kind is called *septicidal.* But there are many instances where the separation takes place along the dorsum or midrib of the carpel rather than along the edges or ventral sutures. This mode of dehiscence is called the *loculicidal,* and it may be observed in the capsule of Blue Flag. In some capsules the dehiscence is both septicidal and loculicidal, and the capsule separates into twice as many valves as there are carpels.

In a third mode of dehiscence the separation takes place along

the ventral or the dorsal sutures or both, but the valves break away from the placentæ, leaving the latter in position, as in the capsules of Cardamom. This is the *septifragal* mode of dehiscence.

In all these types the dehiscence may be either partial or complete, and it may begin at the apex, the most common mode, or it may begin at the base. Now, the mode of dehiscence that occurs in the Poppy capsule, though technically called "porous" or "valvular," is really one of partial septicidal dehiscence, where the opening begins at the top. In the Campanula the dehiscence is valvular, but occurs at the base of the capsule.

Still another mode of dehiscence is seen in that modification of the capsule called the pyxis, where Nature wholly ignores the original sutures, and the opening is transverse or *circumscissile*, as in Portulacca, the Marcgravia, and the South American Lecythis. Moreover, the dehiscence in a few instances takes place without order or by irregular rupture through any part of the pericarp.

(4) *Provision for Dispersion.*—The seeds of the Poppy are very numerous; according to M. C. Cooke, a single capsule may contain as many as forty thousand of them. When ripe they become detached from the placentæ and fall to the bottom of the capsule. But the valves of dehiscence, as has been seen, are at the opposite end; how is it, then, that the seeds escape? It will be observed that the capsule when ripe is erect on the end of a dead but elastic stalk. In a stiff breeze this stalk is swayed to and fro, and when the motion is sufficiently rapid some of the seeds are thrown out of the openings near the apex, and, being small and light, are caught up by the wind and conveyed often to a considerable distance from the parent plant. During every wind-storm the process is repeated, until finally the capsules are emptied.

II. THE FRUIT OF COLCHICUM.—(1) *External Characteristics.*—The brownish capsule is an inch or more long, oblong, abruptly pointed, longitudinally ribbed and furrowed, and between the ribs and furrows somewhat rugose. By observing closely the ribs and furrows there will be obtained clear evidence that the fruit is a three-carpeled pistil. The dehiscence affords further evidence of the same thing. This dehiscence is clearly septicidal, for the seeds are found attached to the edges of the valves.

(2) *Internal Structure.*—Making a cross-section of the fruit

near its middle, preferably before it is quite ripe, and comparing the structure with that observed in the dehiscing capsule, clearest evidence of its three-carpeled character will be found. The three carpellary leaves have evidently been rolled inward at their margins, not only until they have met at the centre, but until they have curved outward again, forming what is called an axile placentation. In dehiscence the carpels have merely separated into their original components.

(3) *Mode of Dispersion.*—Here no elaborate means of dispersal seem to be required. The small brown seeds are not only very hard, but they are also poisonous, so that they are not likely to be devoured by animals. All that is needed is that the capsule should open and expose the seeds to the wind.

III. THE FRUIT OF HYOSCYAMUS.—This fruit may be studied as the type of that modification of the capsule called the *pyxis.* The fruit is enclosed in the persistent, urceolate, five-toothed, hairy calyx, which, however, is not adherent to it and does not properly constitute a part of it.

(1) *External Characteristics.*—Removing the calyx, it will be found that the somewhat urn-shaped fruit has a length of from one to one and one-half centimetres, is usually somewhat two-lobed and rugose, and is dehiscent by a line that runs horizontally around it well toward the top, so that the upper portion comes off like a lid. At the apex of the latter is seen the remnant of the style in the form of a small rounded or conical prominence.

(2) *Internal Structure.*—Removing the lid, the fruit is found to be two-celled and many-seeded, the seeds being attached to placentæ at the axis. It is therefore, as one would be led to expect from its two-lobed exterior, a two-carpeled fruit. The two-celled and two-carpeled character are, however, not necessary to the idea of a pyxis. The pyxis of some species may be one-celled, of others two-, three-, or several-celled. There is, in other words, the same variety in this respect among fruits of this kind as among ordinary capsules.

The dispersion in this species is accomplished in a manner analogous to that in the Poppy. After dehiscence the wind, agitating the plant, will throw out the seeds, which, being small and light, will be sown far and wide.

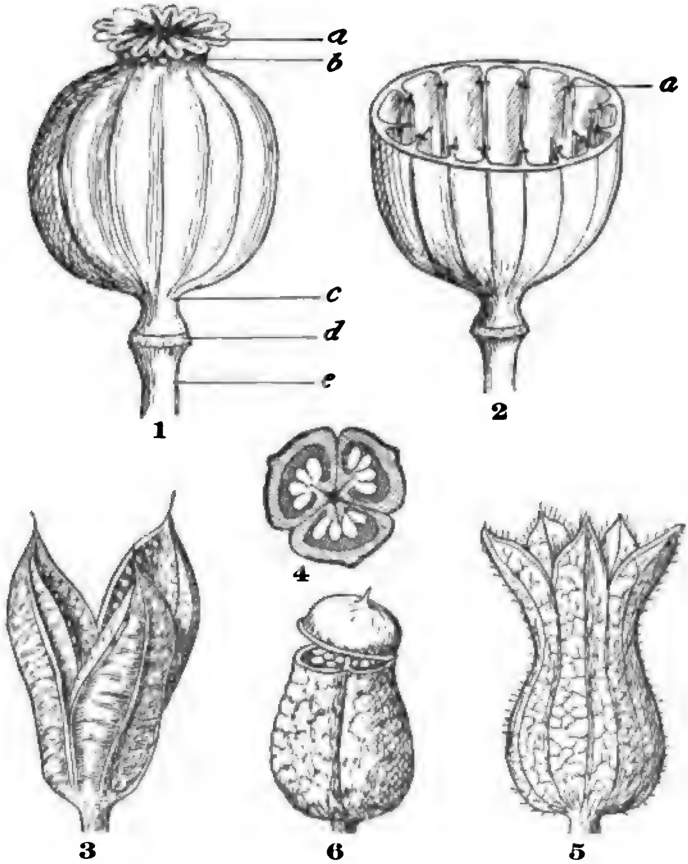


PLATE XXXII., FIG. 1.—Poppy-capsule (about natural size): *a*, stigma; *b*, one of the valves of dehiscence; *c*, stalk of capsule; *d*, portion of receptacle on which sepals, petals, and stamens were inserted; *e*, peduncle.

FIG. 2.—The same in transverse section, showing marginal placentation: *a*, one of the placentæ.

FIG. 3.—Capsule of Colchicum (somewhat enlarged), showing septicidal dehiscence.

FIG. 4.—Transverse section of unripe Fruit, showing axile placentation and three-carpeled structure.

FIG. 5.—Calyx of Hyoscyamus, enclosing pyxis. (Somewhat enlarged.)

FIG. 6.—Pyxis of Hyoscyamus, showing its two-celled and two-carpeled character and its mode of dehiscence.

EXERCISE XXVIII.

FURTHER STUDY OF SYNCARPOUS FRUITS.

FROM the list given at the beginning of the last exercise are selected the following for this exercise: the fruit of the Coriander and that of the Lemon.

I. THE FRUIT OF CORIANDER.—Coriander belongs to the natural order Umbelliferæ, the fruits of which have a close family resemblance and differ quite widely from those of most other plants in several important particulars. The fruits are called *cremocarps*, and a cremocarp may be defined as an inferior, two-carpeled dry fruit that is usually ten-ribbed longitudinally and is provided with oil-tubes or *vittæ*, has an epigynous disk, and, when ripe, splits readily, usually spontaneously, into two symmetrical, one-seeded half-fruits or *mericarps*. Between the primary ridges or *juga* there sometimes occur secondary or intermediate ones. The mericarps not infrequently remain suspended for a time after dehiscence from the top of a slender prolongation of the receptacle, called the *carpophore*. This may be either single or separated into two thread-like portions nearly to its base. The oil-tubes, when present, usually occur in the furrows between the primary ribs or on the commissural surfaces. The two styles are usually persistent and thickened at their bases into bodies called *stylopodia*. The seeds are albuminous, pendulous, and anatropous.

While it is an easy matter to distinguish members of this order from those of other orders by their fruits, the latter also afford the best means of distinguishing the species of the order from each other, since the cremocarps differ not only in shape and size, but also in the number and position of the oil-tubes, in the presence or absence of secondary ribs, in the surface appendages, etc.

The fruits of Coriander, as in most others of the order, occur in compound umbels. The individual fruits are nearly spherical and four or five millimetres long. At the apex of each are observed two stylopodia, each rising to a point, or sometimes still

terminated by the persistent upper part of the style and stigma. Forming a circle about the base of the stylopodia are five small but distinct calyx-teeth. Careful scrutiny will also reveal, interior to these, the scars of the deciduous petals and stamens. The fruit is therefore clearly inferior. The ten primary ribs are straight and distinct, and the ones at the commissure are double. Between each pair of primary ribs are more obscure secondary ones, which are not straight, but wavy or zigzag.

The fruits in this instance do not, as a usual thing, spontaneously separate into their mericarps, but the separation is easily brought about by slight pressure. The commissural faces are then seen to be flat or slightly concave, and on the face of each commissure are two oil-tubes, the only ones this species possesses.

If a transverse section through the middle of the fruit be made, these oil-tubes, whose contents are brown, may easily be distinguished with a magnifying-glass. In this section the seeds are curved or crescentic, with the concave surfaces facing each other in the two mericarps. A longitudinal section of the fruit, running through the middle of the two mericarps, will also show the seed as somewhat curved, and the minute embryo may be seen imbedded in the albumen at the upper end.

The oil-tubes contain the volatile oil which renders the fruits aromatic, and which, in this and most other Umbelliferæ employed in medicine, makes the fruits valuable as stimulants and carminatives.

II. THE FRUIT OF THE LEMON.—This may be taken as typical of the group of fruits popularly called "citrus" fruits, but termed botanically *hesperidia.*

(1) *External Characters.*—At the base is usually found the persistent five-toothed calyx, showing that the fruit is *superior*. At the mammillate apex may be observed the scar of the style, which has withered and fallen away. The fruit is oblong or ellipsoidal in outline, from six to ten centimetres long, and rugose on the surface. Imbedded in the outer portion of the light-yellow pericarp are numerous rounded secretion-reservoirs containing the volatile oil which imparts the peculiar fragrance to the fruit. The fruit is fleshy and indehiscent, and there are on the surface no ridges or furrows to indicate the number of carpels of which it is composed.

(2) *The Internal Structure.*—Making a cross-section through the middle, it will be found that the thickish pericarp is differentiated into two portions—an outer, which is yellow and contains the secretion-vessels already mentioned, and an inner white and spongy portion destitute of glands.

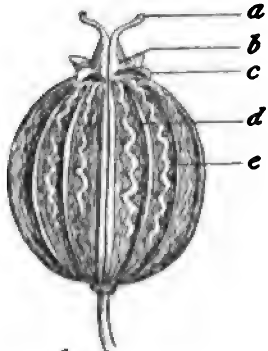
Interior to the pericarp is the pulpy portion, divided by radial partitions into a varying number of compartments. In the inner angle of each compartment or loculus are usually one or two seeds, and these are attached to the axis. The placentation, therefore, is axile, and there are as many carpels in the fruit as there are loculi, which may be from five to fifteen or more.

The pulp which contains the acid juice is structurally altogether different from that of the Cherry, Peach, or, in fact, from that of any other fruits outside the family (Aurantiaceæ) to which the Lemon belongs. The juice is contained in numerous thin-walled sacs which are separate from each other and are borne on the walls of the loculus. By tracing their development they may easily be proved to be hairs which at first are like ordinary simple plant-hairs, but which, as the ovary develops into the fruit, become thick and succulent.

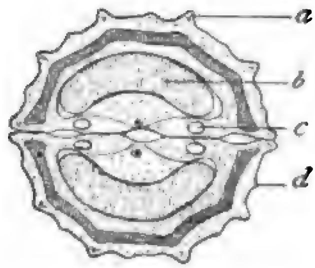
Citrus fruits resemble berries except for this peculiarity of their pulp, which justifies calling them by a different name, that of *hesperidia*.

The seeds have a leathery testa, are anatropous and exalbuminous, and the dicotyledonous embryo is frequently single, but sometimes, as in the orange, there are two or more embryos in each seed. The cotyledons are commonly somewhat unequal, and sometimes there are three or four instead of two. The plumule is usually well developed.

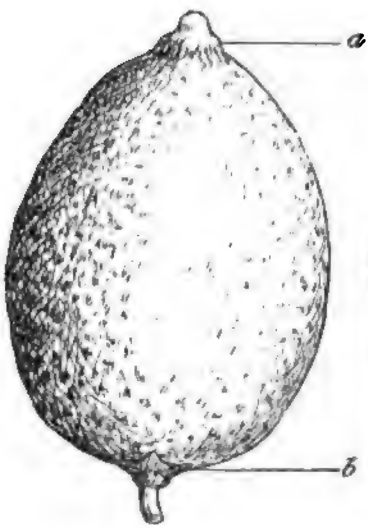
So far as the relation of the structure of this fruit to the dispersion of the plant is concerned, it may be remarked that the volatile oil in the pericarp is probably defensive against the attacks of insects and fungi, while not preventing the fruits from being eaten, when ripe, by larger animals. The seeds, while not specially protected by a hard enclosure, are nevertheless probably rejected, as a usual thing, by animals that feed upon the fruits, by reason of their bitter taste.



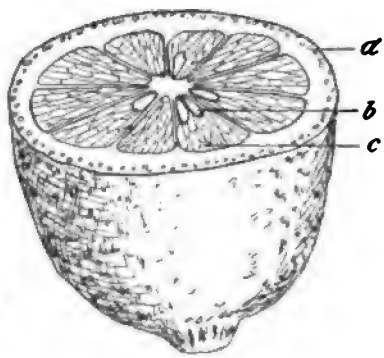
1



2



3



4

PLATE XXXIII., FIG. 1.—Fruit of Coriander (enlarged about 6 times): *a*, one of the stigmas sometimes persisting until the fruit is ripe; *b*, one of the stylopodia; *c*, one of the calyx-teeth; *d*, one of the primary ribs; *e*, one of the secondary ribs.

FIG. 2.—Transverse section through one of the Cremocarps (enlarged about 8 diameters): *a*, one of the primary ribs; *b*, seed; *c*, one of the villæ or oil-tubes: *d*, one of the secondary ribs.

FIG. 3.—Lemon (2/3 natural size): *a*, nipple-shaped apex; *b*, calyx at base.

FIG. 4.—Transverse section of the same, showing placentation: *a*, glandular portion of pericarp; *b*, a seed; *c*, one of the pulp-sacs, modified hairs.

EXERCISE XXIX.

STUDY OF ACCESSORY FRUITS.

THE following are convenient for study: the Strawberry (Fragaria Virginiana, *Mill.*, or F. vesca, *L.*), the Rose (the hips of any one of our common species, as Rosa setigera, *Michx.*, R. Carolina, *L.*, or R. rubiginosa, *L.*), the Mulberry (Morus rubra, *L.*), the Wintergreen (Gaultheria procumbens, *L.*), the Pineapple (Ananassa sativa, *Lind.*), and the Fig (Ficus Carica, *L.*).

From this list are selected for the present study the fruits of the Wintergreen and the Fig.

I. THE WINTERGREEN is an ericaceous plant very common in most portions of the Eastern United States, and it is particularly abundant in those portions of the country which abound in pines or other needle-leaved evergreens. From the thin, trailing stem or rhizome rise vertically, to the height of from three to six inches, slender, usually simple branches which bear a few crowded alternate or apparently whorled evergreen leaves.

The plant bears its white, nodding, urceolate blossoms singly in the axils of the leaves. The blossoming is in June and July, and the scarlet, berry-like fruits are matured in late summer or in early autumn, but persist on the plant until late in the succeeding spring.

(1) *External Characteristics.*—The so-called berries are nearly spherical, about a centimetre in diameter, somewhat depressed and bracteolate at the base, with five fleshy teeth at the apex, and with a simple persistent style.

The five teeth referred to are really the limb of the persistent gamosepalous calyx, which in fruit develops considerably, becomes succulent, acquires a scarlet color, and constitutes the really edible part of the fruit. This is clearly evidenced by a study of the

(2) *Internal Structure.*—On making a transverse section well toward the apex of the fruit there will be observed a five-celled,

many-seeded, dry or non-succulent body, the real fruit, surrounded by a circle of five fleshy pieces having an imbricate arrangement —the calyx-teeth before referred to. Such a section is shown on Plate XXXIV. (Fig. 4), but the fact is even more distinctly seen by examining a longitudinal section, as shown on Plate XXXIV. (Fig. 2); if any further doubt still existed, it could easily be dispelled by tracing the development of the fruit from the flower.

The fruit is, then, in reality an indehiscent capsule with a fleshy accessory calyx, and is not a berry at all, for a berry is an indehiscent fruit with a wholly succulent pericarp—as, for example, the cranberry, gooseberry, and grape. The fruit bears more resemblance to a pome such as the apple, but differs from it in the fact that the calyx is not adnate to the fruit proper, and the latter is dry, not succulent.

(3) *Dispersion.*—Undoubtedly, in this as in most other showy fruits the bright color and the agreeable taste cause the fruit to be eaten by animals. The seeds, on account of their minuteness, are not likely to escape when the fruit is eaten, but, being hard and probably much less digestible than the rest, many of them are likely to survive the action of the gastric juice, and to emerge from the alimentary canal of the animal in a condition fit for germination.

II. THE FIG.—This fruit, easily obtained in the dried form in our markets at all seasons of the year, is best studied by soaking specimens in water to which a little ammonia has been added, to swell them to their original dimensions.

(1) *External Characteristics.*—The fruit is pyriform in shape, smooth or somewhat longitudinally striate on the outside, depressed and with a small aperture at the apex which opens into the hollow interior, and at the base tapering into a woody stem. The rest of the fruit is soft and pulpy—in fact, so far as mere external appearances go, it might easily be mistaken for a fruit essentially like a pear. A careful study of its internal structure and its mode of development, however, shows that the fig is altogether different.

(2) *Internal Structure.*—A longitudinal section through the centre shows that the small aperture at the apex communicates with a considerable cavity in the interior, and the walls of this are lined with numerous small seed-like bodies. These, however, on

close inspection are found not to be seeds, but small fruits (utricles), each with a single seed loosely enclosed in a thin, dry pericarp. Each fruitlet, as may easily be seen by studying its development, is the product of a single small flower.

In examining the Fig in blossom it would be difficult for the novice even to find the flowers, as he would scarcely think of looking for them concealed in the ends of twigs. These twigs, moreover, do not look very different from the ordinary ones, except that they are slightly thickened and pyriform at the apex, and bear just below this thickened portion a few scaly bracts instead of true leaves. The minute aperture at the apex, closed as it is by scales, might easily escape observation altogether.

If a longitudinal section of one of these branches be made, there will be found in the interior hollow a few minute staminate flowers located near the apical aperture, and very numerous small pistillate flowers occupying the remainder of the interior surface. The former consist of a gamosepalous, three-parted calyx and three introrse stamens; the latter also consist of a gamosepalous calyx (which, however, may be from three- to five-parted) and a single one-ovuled pistil which has a style, inserted more or less laterally, and a two-lobed stigma. The flowers are also stalked, and in development the stalks and calyx become fleshy, while the fruit proper becomes dry and utricle-like or achenium-like.

It will thus be seen that what is called the fig is not a single fruit, but a multiple or collective one; but it is also something more, for the greater portion of its bulk is composed of the succulent hollow receptacle. Such a multiple fruit with an accessory receptacle has been called by botanists a *syconium*.

(3) *Mode of Dispersion.*—Regarding this it may be remarked as significant that, besides being attractive and palatable when ripe, the seeds possess laxative properties which doubtless render them more likely to escape digestion, and at the same time ensure their dispersion by frugivorous birds and mammals.

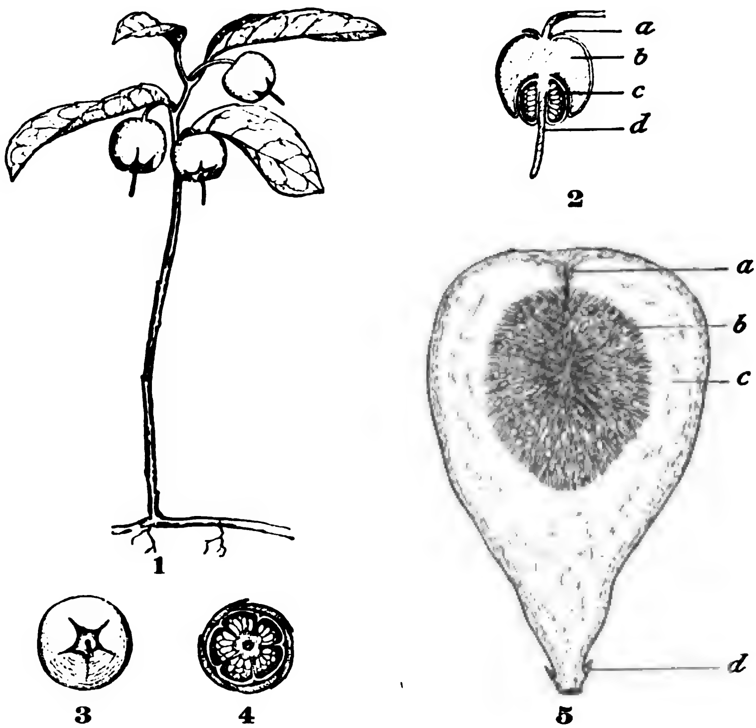


PLATE XXXIV., FIG. 1.—Whole Plant of Wintergreen in fruit (⅔ natural size).

FIG. 2.—Longitudinal section of one of the Fruits (enlarged): *a*, bract at the base; *b*, fleshy calyx; *c*, fruit proper; *d*, persistent style.

FIG. 3.—View of upper end of Fruit, showing the five calyx-teeth, the upper end of the capsule, and the style.

FIG. 4.—View of cross-section through the upper part of one of the Fruits, showing the five-celled, many-seeded capsule surrounded by the calyx.

FIG. 5.—Longitudinal section of a Fig (about natural size): *a*, apical aperture; *b*, one of the fruitlets; *c*, hollow receptacle; *d*, one of the bracts at the base.

FORM FOR THE STUDY OF FRUITS.

I. SIZE.
  1. Length.
  2. Breadth.
  3. Thickness.

II. COLOR.
  1. Exteriorly.
  2. Interiorly.

III. SHAPE.
  1. Globose.
  2. Depressed-globular.
  3. Oblong.
  4. Ovoid.
  5. Conical.
  6. Pyriform.
  7. Flattened.
  8. Winged.
  9. Ribbed.
  10. Lobed.
  11. Nodular.
  12. Irregular.

IV. SURFACE AND APPENDAGES.
  1. Glabrous.
  2. Polished.
  3. Glaucous.
  4. Punctate.
  5. Glandular-hairy.
  6. Rugose.
  7. Scabrous.
  8. Verrucose.
  9. Pubescent.
  10. Puberulent.
  11. Sericeous.
  12. Lanuginous.
  13. Tomentose.
  14. Villose.
  15. Pilose.
  16. Floccose.
  17. Hispid.
  18. Strigose.
  19. Spinose.
  20. Echinate.
  21. Aculeate.
  22. Pappiferous.

V. INTERNAL STRUCTURE.
  1. *Texture of pericarp.*
    (1) Succulent throughout.
    (2) Succulent exteriorly.
    (3) Succulent interiorly.
    (4) Farinaceous throughout.
    (5) Farinaceous exteriorly.
    (6) Farinaceous interiorly.
    (7) Oily throughout.
    (8) Oily exteriorly.
    (9) Oily interiorly.
    (10) Waxy exteriorly.
    (11) Coriaceous throughout.
    (12) Coriaceous exteriorly
    (13) Coriaceous interiorly
    (14) Ligneous throughout
    (15) Ligneous exteriorly.
    (16) Ligneous interiorly.
    (17) Fibrous exteriorly.
    (18) Corneousthroughout.
    (19) Corneous exteriorly.
    (20) Corneous interiorly.
    (21) Bony throughout.
    (22) Bony exteriorly.
    (23) Bony interiorly.
  2. *Number of loculi.*
    (1) Unilocular.
    (2) Bilocular.
    (3) Trilocular.
    (4) Quadrilocular.
    (5) Quinquelocular.
    (6) Sexilocular.
    (7) Multilocular.
  3. *Seeds in each loculus.*
    (1) One.
    (2) Two.
    (3) Several.
    (4) Many.

VI. KIND.
  1. *Inferior.*
  2. *Superior.*
  3. *With accessory organs.*
    (1) Accessory calyx.
    (2) Accessory involucre.
    (3) Accessory receptacle.
  4. *Without accessory organs.*
  5. *Product of single flower.*
    (1) Of one pistil.
      a. Indehiscent.
        Akene.
        Utricle.
        Caryopsis.
        Samara.
        Double samara.
        Glans.
        Cremocarp.
        Drupe.
        Tryma.
        Berry.
        Hesperidium.
        Pepo.
        Pome.
      b. Dehiscent forms.
        Follicle.
        Legume.
        Loment.
        Cochlea.
        Capsule.
          Septicidal dehiscence.
          Septifragal dehiscence.
          Loculicidal dehiscence.
          Porous dehiscence.
        Silique.
        Silicle.
        Pyxis.
    (2) More than one pistil.
      a. Etaerio.
      b. Strawberry.
      c. Hip or cynarrhodium.
  6. *Product of flower-cluster.*
    (1) Sorosis.
    (2) Syconium.
    (3) Strobile.
    (4) Galbulus.

VII. TASTE.
  1. Insipid.
  2. Bland.
  3. Sweet.
  4. Bitter.
  5. Mucilaginous.
  6. Pungent.
  7. Acrid.
  8. Warm.
  9. Burning.
  10. Cooling.
  11. Astringent.
  12. Nauseous.
  13. Prickling.
  14. Saline.
  15. Alkaline.
  16. Acidulous.

VIII. ODOR.
  1. Odorless.
  2. Faint.
  3. Agreeable.
  4. Aromatic.
  5. Mint-like.
  6. Balsamic.
  7. Camphoraceous.
  8. Terebinthinous.
  9. Pungent.
  10. Musky.
  11. Disagreeable.
  12. Irritating.
  13. Nauseous.
  14. Narcotic.
  15. Putrid.
  16. Fetid.

it should be noted that every seed possesses at least two, and usually only two, scars, that of the micropyle and that called the hilum, the latter marking the place where the seed has broken away from its funiculus or from the placenta. One may tell by the relative position of these scars whether the seed is atropous, anatropous, campylotropous, or amphitropous—always an important point to determine. If the seed is straight and the two scars are at opposite ends, the seed is *atropous;* if it is straight and the two scars are adjacent to each other at one end, it is *anatropous;* if straight and the chalaza is at one end, the micropyle at the opposite one, and the hilum intermediate between the two, it is *amphitropous;* and if the seed is bent or curved so that the opposite ends and the two scars are approximated, it is *campylotropous.*

In some seeds the nucellus consists wholly of embryo; that is, the seeds possess no extra food store, and are hence called *exalbuminous,* as was found to be the case with the Cherry; other seeds possess both the embryo and the extra food store: they are described as *albuminous.* In an albuminous seed the albumen or extra food store may be developed either wholly within the embryo-sac or outside of it. In the former case the albumen is called endosperm; in the latter, perisperm. In a few seeds both endosperm and perisperm are present.

I. THE ALMOND SEED.—The fruit of the Almond is drupaceous like the peach and the cherry, only the sarcocarp is less succulent and is not employed for food. The almond of the markets corresponds to the pit of the peach; that is, the outer hard part is endocarp and contains the seed.

(1) *External Characteristics.*—Carefully removing the seed, so as to observe its attachments, it will be noticed that it has on one edge, near its smaller end, a narrow hilum-scar extending up along the edge of the seed from one-third to one-half of the length of the latter. At the small end of the seed, immediately adjoining one end of this scar, is the small but distinct micropyle-scar. These scars being adjacent and the body of the seed not being bent, the seed is known to be anatropous. At or near the large end may be seen a roundish spot, often darker than the rest of the surface, where the two coats still adhere to each other: this is the chalaza. From this point veins are seen to radiate and con-

verge toward the opposite end. On the hilum edge may also be traced a straight line and a slight ridge which connects the hilum and chalaza: this is the raphé.

The general outline of the seed is ovate; it is flattish, somewhat wrinkled from drying, and more or less longitudinally striate. The length is from two to two and one-half centimetres, the width from one to one and one-half centimetres, and the greatest thickness from one-half to three-fourths of a centimetre. The testa is thin and brown; it is also scurfy from large, bladdery, exterior cells.

(2) *Internal Structure.*—Soaking the seed in water for a few hours and removing the coats, the latter are found to be two in number and quite distinct except at the chalaza; the inner one is membranous and white, and covers the white nucellus. The latter is found to consist wholly of embryo; the seed, therefore, is exalbuminous.

The embryo is straight; that is, the radicle and the cotyledons point in opposite directions. The cotyledons are large and thick, constituting much the larger part of the whole embryo. As shown in the illustration (Pl. XXXV., Fig. 2), they are not always equal, but one may be considerably larger than the other. They are usually more or less cordate at the base. The radicle and caulicle, though relatively small, are distinctly recognizable by the naked eye, as is also the plumule, which is well developed.

(3) *Tests.*—Applying iodine solution to a freshly-cut surface, it will be observed that no blue color is developed, and therefore no starch is present. If the solution be strong, however, a brown color is produced, which indicates the presence of proteids. But the great bulk of the food material stored in the embryo consists of fixed oil. The presence of the latter may be proved by thoroughly warming the freshly-cut surface of a seed and rubbing it on a clean sheet of white paper, when a non-volatilizable greasy spot will be left.

II. THE PUMPKIN SEED.—(1) *External Characteristics.*—The seeds are smooth, white, oblong-ovate, strongly flattened, with a raised border extending from the smaller end around the edge to the same end. The hilum and micropyle-scars are located side by side at the smaller end of the seed, and, though not large, are distinct. The chalaza is at the opposite end, but the raphé in the

fully-developed seed merges into the border above described, and is no longer recognizable. The length of the seed is about two centimetres, its greatest breadth about one centimetre, and its greatest thickness about two millimetres.

(2) *Internal Structure.*—The testa is coriaceous in texture and distinct from the thin, membranous, olive-green tegmen, which immediately envelops the embryo, there being no albumen.

The embryo consists of two oblong-ovate or elliptic, equal cotyledons, flat on their applied faces and convex on their exterior ones, each provided with about seven veins radiating from the base to the entire margin.

The caulicle and radicle together form a small, somewhat flattened cone, and the plumule exists only as the merest conical point between the bases of the cotyledons. It is, in fact, but an epicotyl, and not a plumule in the proper sense, no leaves being developed upon it until after germination begins.

Tests show that the seed possesses abundance of albuminous and oily matter, but no starch.

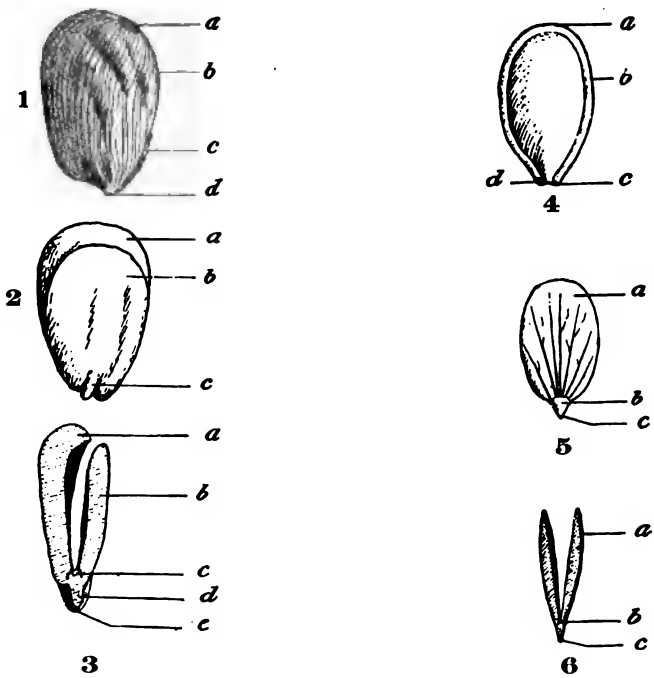


PLATE XXXV., FIG. 1.—Almond Seed (about natural size): *a*, chalaza; *b*, raphé; *c*, hilum; *d*, micropyle.

FIG. 2.—The same with the seed-coats removed, consisting wholly of embryo: *a*, the larger of the two cotyledons partly concealed behind the smaller one, *b*; *c*, the radicle.

FIG. 3.—The same cut lengthwise through the middle of the two cotyledons and the radicle: *a*, larger cotyledon; *b*, smaller cotyledon; *c*, plumule; *d*, caulicle; *e*, one of the projecting lower lobes of the larger cotyledon.

FIG. 4.—Seed of Pumpkin (about natural size): *a*, chalaza; *b*, raised border; *c*, hilum; *d*, micropyle.

FIG. 5.—Embryo of same, showing outer face of one of the cotyledons, *a*, the caulicle, *b*, and the radicle, *c*.

FIG. 6.—Embryo of same, cut vertically through the middle of the cotyledons: *a*, one of the cotyledons; *b*, the epicotyl, scarcely yet developed into a plumule; *c*, the radicle.

EXERCISE XXXI.

STUDY OF ALBUMINOUS SEEDS.

SEEDS of the following plants are not difficult to obtain and are good for study: the Common Morning-glory (Ipomæa purpurea, *Lam.*), Stavesacre (Delphinium Staphisagria, *L.*), the Yellow Pond-lily (Nuphar advena, *Ait.*), Sweet Cicely (Osmorrhiza longistylis, *DC.*), Nux Vomica (Strychnos Nux-vomica, *L.*), Datura Stramonium, *L.*), Castor Bean (Ricinus communis, *L.*), Croton-oil Plant (Croton Tiglium, *L.*), Yellow Dock (Rumex crispus, *L.*), and Black Pepper (Piper nigrum, *L.*).

For this exercise the Castor Bean and Black Pepper are selected.

I. THE CASTOR BEAN.—These seeds are easily obtainable from druggists or from dealers in agricultural seeds.

(1) *External Characteristics.*—They are ovate or elliptical in outline, convex on one side and on the other flattish, or rather with two flattish surfaces inclined at a very obtuse angle to each other. The two surfaces are shown respectively in Figures 1 and 2 (Pl. XXXVI.). The seeds measure from one to one and one-half centimetres in length, from six to nine millimetres in width, and from four to six millimetres in thickness. At one end is a rounded or more or less two-lobed strophiole or caruncle which partly conceals the hilum and micropyle, located side by side at the same end. The chalaza is usually evident to the eye as a somewhat elevated point near the opposite end. Between the hilum and the chalaza, on the flatter side of the seed, may be traced the straight raphé, which appears as a slight ridge.

The whole surface, except the brownish or yellowish strophiole, is maculate with irregular reddish-brown spots and lines on a light-brown or grayish background. The surface is also smooth and polished.

(2) *Internal Structure.*—It is usually best, as a preliminary to the dissection of a seed, to soak it for a few hours in water, but in this instance it is hardly necessary. Removing the outer coat

or testa, it is found to be thickish, hard, brittle, and of a chocolate-brown color in the interior. The tegmen is thin, membranous, and silvery-white.

The nucellus consists of a white, oily albumen enclosing a well-developed, straight embryo. Its structure is best demonstrated by first placing the edge of the knife at one end, in a direction parallel to its longer transverse diameter, and exerting gentle pressure upon it. This will usually cause the nucellus to split between the cotyledons with very little injury to the parts, and showing well their structure and relations. Plate XXXVI. (Fig. 3) shows the parts thus exposed.

The embryo consists of two elliptical, entire-margined, thin, cordate cotyledons, each with three ribs radiating from its base and branching to form a network. The caulicle and radicle together form a small terete or somewhat fusiform body, the radicular end of which lies close to the exterior surface of the albumen, adjacent to the micropyle.

The albumen possesses no starch, but abundance of fixed oil and numerous large aleurone-grains containing crystalloids and globoids. These, however, cannot be seen without the aid of a compound microscope.

One can hardly fail to notice that when the seeds lie upon the ground, convex side up, they bear a close resemblance to some beetles. It has been suggested that this mimicry may be of advantage to the species in aiding the dispersion of the seeds, birds picking them up and swallowing them by mistake for insects. In this case the cathartic properties of the seeds would probably prevent digestion, and they would be dropped in fit condition for germination.

II. THE BLACK-PEPPER SEED.—Black Pepper, as we obtain it in the market, is the dried unripe fruit of the plant, and the fruit, often called a berry, is really a one-seeded drupe. The black, wrinkled, outside portion is the shrunken sarcocarp enclosing a rather thin but hard putamen, which in turn encloses the seed. But, owing to the time of gathering, the seed of the Black Pepper is seldom in a condition fit for study. White Pepper is more favorable for this purpose, for this is only the fruit of the same species of plant which has been permitted to become ripe, or nearly so, and which has been deprived of its sarcocarp. The

grains should be soaked for several hours in water, and then longitudinal sections should be made of them.

Internal Structure.—Interior to the thin seed-coats, which lie in close contact with the wall of the endocarp, is a large quantity of albumen and a relatively minute embryo. The seed is erect and orthotropous, and the embryo is straight, with its radicle close to the micropyle. But a point worthy of special note is the fact that the albumen is not all alike: it is divided into two distinct portions, separated from each other by a sharp line and differing from each other in texture and color. One of them is light-colored, even white, and occupies a small area at the apex of the seed; it is the part in which the embryo is imbedded. The other is darker, harder, freely besprinkled with secretion-cells, and occupies all the rest of the interior of the seed. These two portions of the albumen, though serving the same purpose, are really quite different in their origin: the former is the endosperm, so called because it is developed within the embryo-sac of the ovule while the embryo is developing; the latter is the perisperm: it is equally a food store, but is developed outside the embryo-sac in the nucellus.

In the great majority of seeds that possess an albumen the latter consists of endosperm only, the embryo-sac absorbing all the rest of the nucellus into itself in the process of its development; in a few instances, as in Pepper, both the embryo-sac with its contents and that portion of the nucellus exterior to the embryo-sac develop *pari passu*, and both endosperm and perisperm are found in the mature seed; and in a few other cases the albumen consists of perisperm only, the endosperm at first developed being absorbed by the embryo before the seed matures. This is the case with the Canna of our gardens.

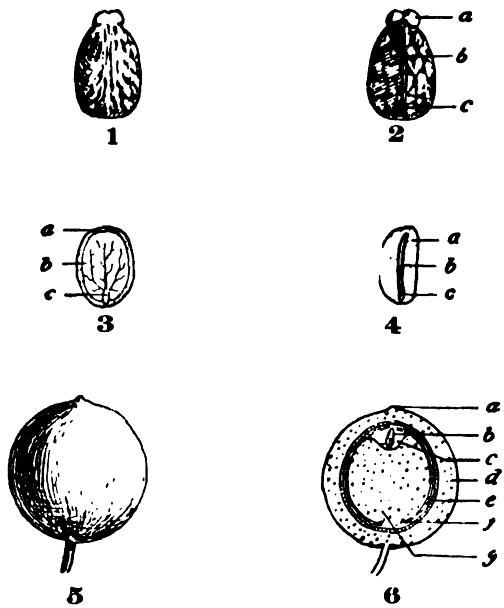


PLATE XXXVI., FIG. 1.—Castor Bean (about natural size): view of convex surface.

FIG. 2.—The same: view of fatter of the two sides: *a*, strophiole; *b*, raphé; *c*, chalaza.

FIG. 3.—Nucellus of Castor Bean, laid open so as to show embryo: *a*, albumen; *b*, one of the cotyledons; *c*, caulicle.

FIG. 4.—Nucellus of Castor Bean, cut vertically in such a manner that the section passes through the middle of both cotyledons: *a*, albumen; *b*, one of the cotyledons; *c*, caulicle.

FIG. 5.—Drupe of Black Pepper (magnified about 3 diameters).

FIG. 6.—The same in longitudinal section: *a*, apex of fruit, showing scar of style; *b*, embryo; *c*, endosperm; *d*, sarcocarp containing oil-cells; *e*, putamen or endocarp; *f*, seed-coats; *g*, perisperm.

EXERCISE XXXII.

STUDY OF SEEDS: MONOCOTYL AND DICOTYL EMBRYOS.

AMONG seeds having monocotyledonous embryos the following are suitable for study: the Indian Corn (Zea Mays, *L.*), the Wheat (Triticum vulgare, *Villars*), the Oat (Avena sativa, *L.*), the Barley (Hordeum distichon, *L.*), the Canna (Canna edulis, *Ker*), the Date Palm (Phœnix dactylifera, *L.*), the Cocoanut Palm (Cocos nucifera, *L.*), and the Water Plantain (Alisma Plantago, *L.*).

Among those with polycotyledonous embryos almost any species of the genus Pinus may be selected, but especially those with large seeds, such as Pinus monophylla, *Torr.*, Pinus flexilis, *James*, Pinus Torreyana, *Parry*, and Pinus ponderosa, *Douglass*.

I. A SEED HAVING A MONOCOTYLEDONOUS EMBRYO.—A selection is made of the seed of the Indian Corn. What is commonly called the seed, however, is really a one-seeded fruit whose pericarp-wall is thin and closely adherent to the coats of the seed. Such a fruit is called a *caryopsis*. That of the Corn is one of many similar fruits aggregated on a common receptacle popularly called the "cob." The so-called "tassels" of the Corn are the clusters of staminate flowers; the "silks" that protrude from the young "ear" are the styles and stigmas; the "kernels" (fruits) are the ripened ovaries; and the "husks" are bracts which subtend the pistillate inflorescence, and, persisting, form the covering of the fruits until they are ripe.

There are, as is well known, a great many different kinds of Maize, but all of them, from the most pigmy varieties of "popcorn" to the giant "dent corn," are probably but varieties of a single species.

(1) *External Characteristics.*—In the larger varieties of Field Corn—Yellow Dent, for example—the fruits may be twelve or fifteen millimetres long by ten or twelve millimetres wide and five or six millimetres thick. The sides are more or less flattened by the mutual pressure of the grains during growth. On one of

the flat faces is a shallow depression, oval or ovate in outline, beginning near the hilum and extending about two-thirds the length of the grain. It is usually lighter in color than the rest, and marks the position of the embryo. Thus the seed, aside from its coats, is composed of a large quantity of albumen against one side of which is lodged the relatively small embryo. The hilum- and micropyle-scars are located at one end, the narrower one, and near together, and since the body of the seed is not bent, it is anatropous.

Plate XXXVII. (Fig. 1) shows a kernel of Yellow Dent Corn about twice the natural size. *a* is the depression in which lies the embryo, and *b* and *c* are respectively the micropyle- and hilum-scars.

(2) *Internal Structure.*—If one of the grains be soaked for a few hours in tepid water to facilitate cutting, and a vertical section be made in such a manner that it passes medially through the embryo, the structure shown in Plate XXXVII. (Fig. 2) will be revealed. At the top is a depression, shown at *a* in the figure. The exterior membrane is the pericarp-wall, interior to which, without any intervening space, are seen the rudimentary seed-coats. At *c* is the dense horny albumen whose cells are closely packed with starch-grains, and at *b* a less dense and more farinaceous portion. At *d* is shown the large body often called the *scutellum*, much larger than all the rest of the embryo put together. It has by some been regarded as a part of the axis, but it is really an outgrowth from the base of the cotyledon, and should therefore be regarded as a part of it. It almost completely enwraps the rest of the embryo and supplies nutriment for its growth, absorbing the food materials from the endosperm, with which it is in contact. The cotyledon proper is shown at *m*, and it fits over the well-developed plumule like a candle-extinguisher. The plumule is shown at *e*, the caulicle or axis at *f*, the radicle at *g*, and the root-sheath or *coleorhiza*, an organ not occurring except in monocotyledonous embryos, at *i*.

If a grain be allowed to germinate until the radicle and plumule have emerged from their enclosure, the relation of parts will be understood better. Such a grain is shown in Figure 3 (Pl. XXXVII.). The root-sheath, pierced by the growing radicle, is shown at *d;* at *e* adventitious roots destined soon to replace

the primary root, which early ceases to grow, are beginning to emerge from the scutellum; and at a is shown the plumule, fast developing into a leafy shoot.

Now, what are the most essential differences between dicotyledonous embryos, such as have already been studied, and monocotyledonous ones like that of Maize? (1) There are in the former two opposite and usually equal cotyledons, while in the latter, if more than one leaf be developed in the embryo, they are alternate, and the one lowest down on the axis is much larger and envelops the rest. (2) In the great majority of monocotyledonous embryos a root-sheath is present, but not in dicotyledonous ones. (3) In germination the portion of the caulicle below the cotyledon, called the *hypocotyl*, does not elongate, but remains short, the growth of the stem in length being due chiefly to the elongation of that portion above the cotyledon, called the *epicotyl*. This is expressed by saying that the germination is *endorhizal*. In dicotyledonous embryos, on the other hand, the hypocotyl usually elongates more or less, often very considerably, as well as the epicotyl. This is expressed by saying that the germination is *exorhizal*. (4) The germination of a monocotyledonous embryo gives rise to a stem which, near its base at least, is nearly always obconical in form; that is, the larger diameter is toward the apex rather than at the base, the reverse of what it is in the stem developed from a dicotyledonous embryo. (5) In nearly all monocotyledonous embryos the primary root stops growing at an early period after germination, and in some instances scarcely develops at all, being replaced functionally by the growth of lateral or adventitious roots. These sometimes may even be recognized in the embryo before germination. In dicotyledonous embryos, on the other hand, the primary root usually persists longer, frequently throughout the life of the plant, giving rise to huge tap-roots and an extensive root-system of which it is the axial portion.

These differences in the embryos form the basis of the division of angiospermous plants into two great sub-classes, the monocotyls and the dicotyls, which also differ from each other in many other particulars to which in previous Exercises attention has been called—namely, in the structure of their roots, in the structure and growth of their stems, in the venation of their leaves, and in the numerical plan of their flowers.

II. A Seed having a Polycotyledonous Embryo.—The seeds of Pinus monophylla, and those of one or two other species of Pine from the Pacific coast, are now sometimes seen in our markets under the name of "piñons," as they are coming to be appreciated as articles of food.

These seeds, like those of all other members of the Pine family, are borne in a scaly fruit called a cone or *strobile*, and each seed is the product of a naked ovule, two ovules being usually borne on the inner face of each scale of the cone. The name *Gymnospermæ* is applied to the great class of plants of which the Pines are the most conspicuous and important members, because the ovules are exposed, or not enclosed by a carpellary leaf or leaves. All other flowering plants are grouped in one class, and this is called *Angiospermæ*, because the ovules are enclosed by a carpellary leaf or leaves. Angiosperms, in other words, have ovaries, while gymnosperms have none.

(1) *External Characteristics.*—The seeds of Pinus monophylla are wingless, oblong, oval or ovate in outline, somewhat flattened on one or more sides, and more or less pointed, with a minute scar, the micropyle-scar, at one end. The seed is often faintly marked by two narrow longitudinal ridges on opposite sides, usually more distinct near the narrower end. The length is from twelve to sixteen millimetres, and the greatest thickness from six to eight millimetres. The exterior is smoothish and brown.

(2) *Internal Structure.*—Carefully removing the hard outer coat of the seed, the nucellus is found to be invested in a thin, membranous, reddish inner coat, which is usually more distinctly marked than the outer by the longitudinal ridges already referred to. Removing this, the nucellus is observed to be white, smooth, and perforated at the micropylar end by a small aperture.

Cutting the nucellus longitudinally through the middle of this aperture, it is found to be composed of a straight embryo imbedded axially in a rather copious albumen, as shown on Plate XXXVII. (Figs. 5 and 6). The embryo, cut longitudinally, separated from the albumen, and magnified, is shown on Plate XXXVII. (Fig. 7). Attached to its radicle end at *a* are some appendages of cobwebby appearance: these are the remains of the suspensors and of other embryos which have failed to develop. When in their natural position they lie in a cavity of the albumen at

the radicular end of the embryo, and are also shown on Plate XXXVII. (Fig. 6, *b*). At *b* (Pl. XXXVII. Fig. 7) is the radicle; at *c*, the caulicle; at *d*, a small conical prominence representing the plumule, though it consists wholly of a portion of the axis (epicotyl), no leaves being as yet formed upon it; and at *e*, one of the several cotyledons. These, in this species, range in number from six to ten, and form a whorl.

In the cross-section of the seed, shown in Figure 8 (Pl. XXXVII.), the section passes through the cotyledons transversely. In this instance they are nine in number, arranged, it will be seen, in a circle. A minute dot is perceptible in each cotyledon, the beginning of the single vein that traverses it when mature.

Except for the number of cotyledons, this embryo is in all essential respects like the dicotyledonous ones already studied. In fact, in many of the Gymnospermæ the embryos do not even possess this difference, having but two cotyledons. The mode of germination is also essentially like that of dicotyledonous embryos.

Though the Gymnospermæ are on the whole lower in the life-scale than either monocotyls or dicotyls, judging by their embryos and by the structure of their stems, which are closely similar to those of dicotyls, one may conclude that they are more nearly allied to the latter group than to the former.

It should be noted that there are a few cases among plants that are really dicotyls where one of the cotyledons becomes aborted, as in Abronia; in some other rare instances—as in Cuscuta, for example—both cotyledons disappear; and in a few instances also the cotyledons become abnormally multiplied, or polycotyledonous. Embryos of the Lemon, for example, have been seen with as many as four cotyledons, though the normal number is two.

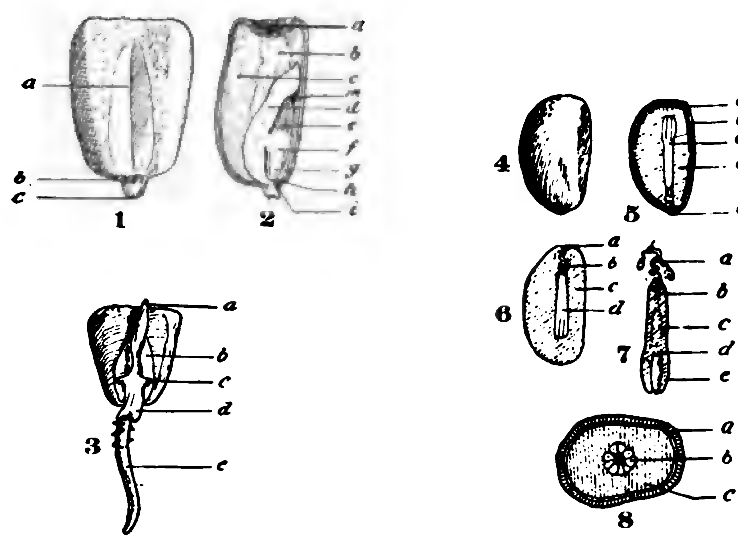


PLATE XXXVII., FIG. 1.—A Grain of Yellow Dent Corn (about twice natural size): *a*, depression on one side, in which lies the embryo; *b*, micropyle; *c*, hilum.

FIG. 2.—One of the grains in longitudinal section: *a*, depression at top of grain; *b*, lighter and less dense portion of endosperm; *c*, denser portion; *d* and *h*, portions of scutellum; *e*, plumule; *f*, axis or caulicle; *g*, radicle; *i*, root-sheath or coleorhiza; *m*, cotyledon.

FIG. 3.—A Grain of Maize in process of germination: *a*, plumule; *b*, portion of scutellum; *c*, an adventitious root; *d*, root-sheath through which the primary root, *e*, has burst.

FIG. 4.—Seed of Pinus monophylla (enlarged about 1½ diameters).

FIG. 5.—The same cut longitudinally, showing internal structure: *a*, outer seed-coat; *b*, inner coat; *c*, embryo; *d*, albumen; *e*, micropyle.

FIG. 6.—Nucellus of Seed separated from the seed-coats and laid open longitudinally: *a*, opening at micropylar end; *b*, remains of embryos that did not develop, and of suspensory filaments; *c*, albumen; *d*, embryo.

FIG. 7.—An Embryo removed from its cavity in the albumen (considerably magnified): *a*, suspensory filaments and rudimentary embryos; *b*, radicle with root-cap already formed; *c*, caulicle; *d*, conical apex of the stem; *e*, one of the several cotyledons.

FIG. 8.—Transverse section of one of the Seeds cutting through the Cotyledons: *a*, outer seed-coat; *b*, one of the cotyledons; *c*, albumen.

FORM FOR THE STUDY OF SEEDS.

I. SIZE.
  1. Length.
  2. Breadth.
  3. Thickness.

II. COLOR.
  1. Exterior.
  2. Interior.

III. SHAPE.
  1. Globose.
  2. Discoid.
  3. Lenticular.
  4. Cylindrical.
  5. Prismatic.
  6. Pyramidal.
  7. Three-sided.
  8. Conical.
  9. Ovoid.
  10. Crescentic.
  11. Reniform.
  12. Flattened.
  13. Polyhedral.
  14. Lobed.
  15. Nodular.
  16. Irregular.

IV. SURFACE AND APPENDAGES.
  1. Smooth.
  2. Polished.
  3. Rugose.
  4. Reticulate.
  5. Alveolate.
  6. Tuberculate.
  7. Scabrous.
  8. Verrucose.
  9. Pubescent.
  10. Puberulent.
  11. Sericeous.
  12. Lanuginous.
  13. Tomentose.
  14. Villose.
  15. Strigose.
  16. Spinose.

V. EXTERNAL STRUCTURE.
  1. *Comose.*
    (1) Coma at hilum only.
    (2) Coma at hilum and along raphé.
    (3) Coma covering most of surface.
  2. *Arillate.*
    (1) Color of aril.
    (2) Aril fleshy.
    (3) Aril fibrous.
    (4) Aril entire.
    (5) Aril branching.
    (6) Size of aril.
      a. Large.
      b. Small.
  3. *Carunculate.*
    (1) Color of caruncle.
    (2) Caruncle large.
    (3) Caruncle small.
  4. *Atropous.*
  5. *Campylotropous.*
  6. *Amphitropous.*
  7. *Anatropous.*
  8. *Shape of hilum-scar.*
    (1) Circular.
    (2) Oblong.
    (3) Linear.
    (4) Curved.
    (5) Triangular.
    (6) Conspicuous.
    (7) Inconspicuous.
  9. *Micropyle-scar.*
    (1) Conspicuous.
    (2) Inconspicuous.
    (3) Adjacent to hilum.
    (4) At opposite end from hilum.
    (5) Midway between opposite end and hilum.

VI. INTERNAL STRUCTURE.
  1. *Testa.*
    (1) Homogeneous.
    (2) Differentiated into layers.
    (3) Texture.
      a. Membranous.
      b. Thick.
      c. Mucilaginous exteriorly.
      d. Fleshy.
      e. Leathery.
      f. Woody.
      g. Horny.
      h. Bony.
  2. *Tegmen.*
    (1) Membranous.
    (2) Distinct.
    (3) Coalescent with testa.
    (4) Wanting.
  3. *Nucellus.*
    (1) Composition.
      a. Exalbuminous.
      b. Albuminous.
    (2) Albumen.
      a. Composition.
        Endosperm.
        Perisperm.
      b. Quantity.
        Copious.
        Equal.
        Scanty.
      c. Position.
        Surrounding embryo.
        Surrounded by embryo.
        To one side of embryo.
      d. Texture.
        Mealy.
        Oily.
        Horny.
        Bony.
        Containing starch.
        Without starch.
    (3) Embryo.
      a. Kind.
        Monocotyl.
        Dicotyl.
        Polycotyl.
        Acotyl.
      b. Parts recognizable.
        Radicle.
        Caulicle.
        Cotyledons.
        Plumule.
      c. Position.
        Straight.
        Plicate.
        Curved.
        Coiled.
        Cotyledons.
          Accumbent.
          Incumbent.
          Number.
          Texture.
            Membranous.
            Thickish.
            Thick.
          Shape.
            Linear.
            Oblong.
            Elliptical.
            Ovate.
            Obovate.
            Lanceolate.
            Oblanceolate.
            Clavate.
            Cordate.
            Lenticular.
            Irregular.
            Entire.
            Lobate.
          Composition.
            Starchy.
            Without starch.
          Germination.
            Epigeal.
            Hypogeal.

PART II.

VEGETABLE HISTOLOGY.

INTRODUCTION.

THE MICROSCOPE AND ACCESSORY APPARATUS TO BE USED IN THIS COURSE.

THE MICROSCOPE.

THE essential parts of the compound microscope are the following:

(1) *The stand,* or that part of the instrument which holds in position the optical parts and the object to be examined. It may be quite simple or very complicated in its construction, according to the uses to be made of it or the fancy of the user, but for the purpose of these exercises a simply-constructed stand is preferable as being less expensive, more readily understood, and more easily manipulated. It should, however, be substantially and carefully made, so as to admit of the use of high powers and not be liable to be easily disarranged. A stand of small or moderate size, built after the so-called Continental model, is preferable for botanical work to one of larger size, both because more convenient to handle and because, on account of the frequent application of test-reagents to tissues undergoing investigation, the stage of the instrument must be horizontal, which necessitates an upright position of the stand. If, therefore, the stand were a large one, to work with it would be both inconvenient and tiresome. There are now many different instruments to be had, answering well the requirements, the product of both American and European factories.

The construction and the parts of the stand are best understood by reference to the accompanying illustration (Fig. 2). The tube or combination of tubes holding the optical parts is called the

body, indicated at A in the figure. The interior tube (B), called the *draw-tube*, slides smoothly within the outer for the purpose of varying the distance between the eye-piece (C) and the objective (G), which distance varies within certain limits the magnifying power of the combination. The body is supported by an *arm* (F) rigidly connected with the *stage* (H). At D, where the body is connected with the arm, is a rack and pinion by means of which the body may be raised or lowered. This constitutes what is called the *coarse adjustment*, and it should be constructed with the greatest care that the movements be smooth and true, without liability to derangement. The coarse adjustment should also be so constructed as to compensate for wear, and the rack should be long enough to permit at least six centimetres working distance between the stage and the front of the objective. The oblique rack-work is no doubt preferable to the ordinary form, giving, when well constructed, greater steadiness of motion. At E is the head of a fine-threaded screw by means of which the whole body of the instrument may be raised or lowered very gradually through a short distance. This screw is used in focusing with high powers, and is hence called the *fine adjustment*. This part of the instrument also requires especial care in its construction, so that lost motion may be avoided and that the adjustment may not easily be impaired by use.

The stage should be commodious—not less than seven centimetres from front to back, and not less than eight centimetres from right to left. The upper surface, which should be faced with either vulcanite or glass, so that it may not be acted upon by corrosive reagents, should be very rigid and firm, and its plane should be exactly at right angles to the optical axis of the instrument. The central aperture, through which light is admitted from below for illuminating the object, should be not less than two centimetres in diameter. This aperture should be provided with diaphragms for regulating the light. The best form of diaphragm, because the most convenient in adjustment, is the iris diaphragm. On the upper surface of the stage are two spring-clips for holding the object-slide in position.

To an extension of the arm below the stage is attached the *illuminating mirror* (I). This should have a diameter of about five centimetres, and one of its faces should be plane, the other

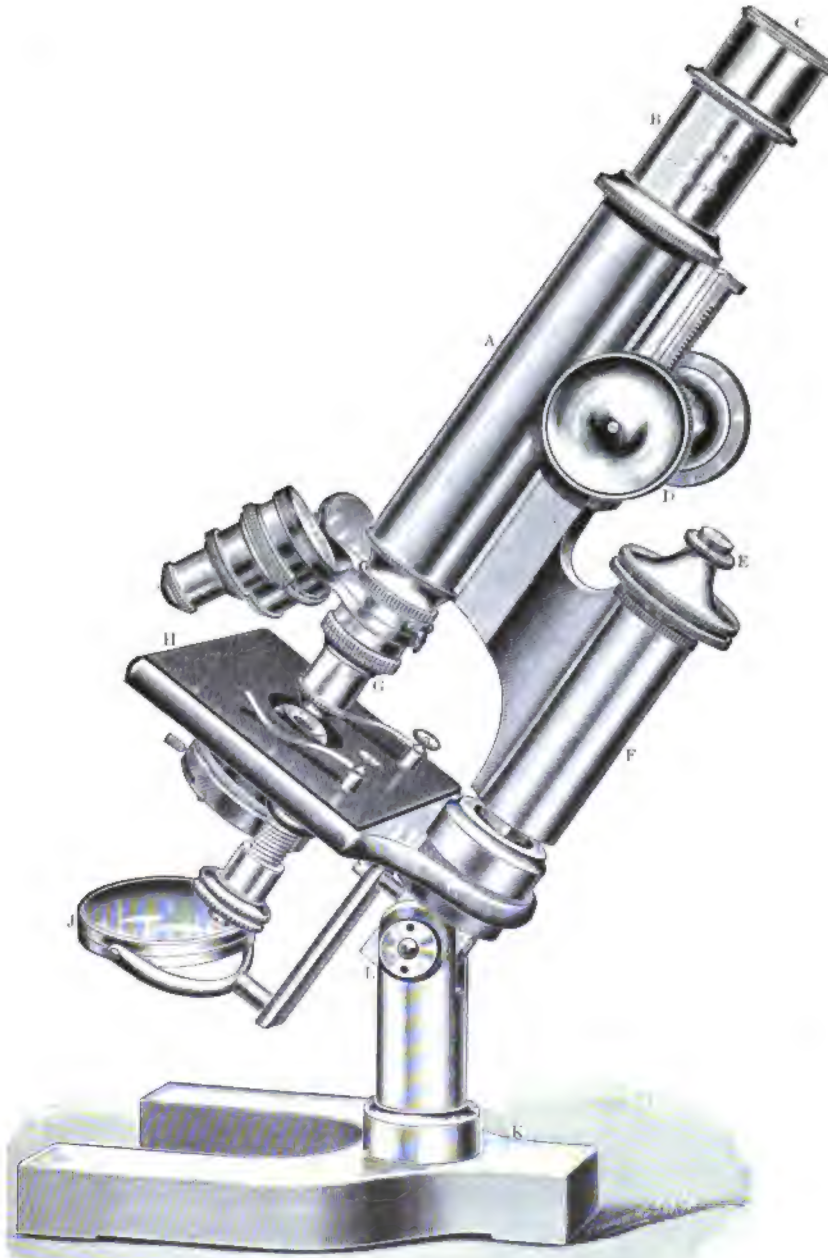


FIG. 2.—Continental Microscope (Bausch & Lomb Optical Co.).

concave. It should be adjustable to any angle, and be suspended on a bar which is both capable of swinging in the vertical plane to secure either direct or oblique illumination, and extensible, so that the concave mirror may be adjusted for the use of either parallel or diverging rays.

As an addition to the illuminating apparatus a condenser of the Abbé type is a great convenience, though, for botanical work, not a necessity.

The part of the stand which supports the stage, arm, and body with the optical parts is called the *pillar*. It should be jointed as shown at L, so as to permit of the inclination of the body at any angle. The pillar in turn is supported by a heavy piece of metal called the *base* (K). This should be so shaped, and the position of the pillar so adjusted, that the instrument will be perfectly steady in any position of the body or stage.

Another piece of apparatus to be regarded as a part of the stand is so convenient that it must not be omitted from the description of a stand suitable for work in a botanical laboratory : this is a double or triple nose-piece for holding two or more objectives at a time. With this simple revolving arrangement the great loss of time consequent on screwing in and screwing off objectives, as well as the risk of breakage, is avoided.

(2) *The optical parts* consist of two kinds, *eye-pieces* and *objectives.*

The eye-piece, as the name implies, is the lens or combination of lenses used next the eye of the observer, and indicated at C in the illustration. In its ordinary form, the Huyghenian, it consists of two plano-convex lenses, one behind the other, with their plane surfaces toward the eye, and placed at a distance from each other equal to half the sum of their focal lengths. The lens next the eye is called the *eye-lens*, that farthest away from it the *field-lens*, and between these, in the focus of the eye-lens, is a diaphragm to shut off extreme rays and such others as may be reflected from the sides of the tube. In order to reduce internal reflection to the minimum, the interior not only of the eye-piece tube, but also that of all others through which the rays from the front lens of the objective pass, is painted a dead-black.

The eye-pieces are so constructed as to fit rather loosely in the eye-end of the tube and to be readily interchangeable. Several

different ones may be used, giving different magnifying powers. The common mode of rating them is by their focal length. The most serviceable are the two-inch, the one-and-a-half-inch, and the one-inch, or, if German or French microscopes are employed, the Nos. i., ii., and iii. eye-pieces.

The objectives are the lenses or combinations of lenses which screw into the front end of the tube, or next the object, whence the name *objective*. One is shown at *G* in the illustration. As a matter of fact, the objectives of all really serviceable microscopes are combinations of two or more lenses and of two or more different kinds of glass, very carefully ground and polished and with their curvatures very accurately adjusted each to the other, so as to give a clear and faithful image of the object—a result which could not be accomplished by means of a single lens. Objectives require, therefore, great skill in their manufacture, and constitute the most expensive parts of the microscope. This is especially true of the high powers, where the combinations must be very complex in order to give the most perfect results.

Objectives of many different powers are manufactured, and these too are rated according to their equivalent focal length. The most serviceable for botanical purposes are a one-inch or a two-third-inch for a low power and a one-sixth-inch or a one-eighth-inch for a high power. These, with the eye-pieces mentioned, will permit of a range of powers from about forty or fifty diameters to six hundred or eight hundred diameters—amply sufficient, if the objectives are of good quality, for most of the work that needs to be done by the student of vegetable histology.

(3) *Estimation of Magnifying Power.*—The magnifying power of a compound microscope may be roughly calculated as follows: Suppose the tube to be of such a length that the distance in a straight line from the object when in focus to the distal end of the eye-piece is ten inches, and that the two-inch eye-piece and the one-inch objective are in position. Ten inches being the normal length of distinct vision, an objective that focuses an object at one-inch distance practically brings it ten times nearer, and therefore magnifies it ten diameters. The same reasoning applies to the eye-piece, which magnifies the image produced by the objective, and, as the eye-piece in this case magnifies five diameters, the magni-

fication produced by the combination is five times ten, or fifty, diameters.

In like manner, other conditions remaining the same, if there be substituted for the optical parts just mentioned the one-inch eye-piece and the one-eighth-inch objective, the magnification will be eight hundred diameters.

If, without changing the optical parts, the tube of the microscope be lengthened, the magnification of the objective will be increased; if the tube be shortened, the magnification will be decreased; and the magnifying power of the combination will be increased or decreased in nearly, though not quite, the same proportion.

Since, however, the objectives and the eye-pieces are not always correctly rated by their makers, a more exact way of determining the magnifying power of the different combinations is by measuring them directly by means of a stage micrometer and a camera lucida. The stage micrometer consists of a very fine scale accurately ruled on a glass slide or cover-glass. This is placed on the stage and the microscope focused upon the lines. The camera lucida is then placed in position on the eye-piece, when the lines may be seen projected on a sheet of paper placed beside the microscope, and their image may be drawn. That the result may be correct, the drawing-paper must be placed at right angles to the direction in which the object is seen by the eye, and at the same distance from it as the micrometer lines on the stage. Suppose, as a practical example, that the lines on the micrometer are known to be precisely one-one-hundredth millimetre apart, while those in the magnified drawing made of them are five millimetres apart; what is the magnifying power of the combination used? The question is easily answered, for, clearly, the apparent distance measured is just five hundred times as great as the real distance between the lines; the magnifying power must therefore be five hundred diameters.

It is not even necessary to employ a camera lucida for the purpose of determining the magnification unless results of great precision are required. It may be done with a close approximation to accuracy with no other apparatus than a good stage micrometer and a foot-rule, by the following process: Focus the micrometer on the stage, and place beside the latter, on the same level

as the micrometer and parallel to its scale, the foot-rule, preferably one having a white surface ruled with black lines, and then look with one eye through the microscope at the scale on the stage, at the same time keeping the other eye open. Both scales will be seen simultaneously, and may be directly compared.

Suppose, for example, that the lines on the micrometer scale, which are known to be, say, one-one-thousandth of an inch apart, appear through the microscope to be precisely one inch apart as measured by the foot-rule: the magnifying power used must therefore be one thousand diameters.

Accessory Apparatus.

The following may be regarded as necessities:

(1) *A stage micrometer*, preferably one ruled according to the metric scale. One millimetre ruled into one hundred equal parts is a very convenient scale for most purposes.

(2) *A section knife* for making thin sections of tissues. The most convenient for ordinary work is a good razor ground flat on one side and slightly concave on the other, but not too thin, and with a straight edge. It should be kept well sharpened, and the student would do well to provide himself also with a good hone and strop.

(3) *A graduated ruler* such as the one described above, or preferably one with the English scale on one edge and the metric scale on the other. Such a ruler is highly useful not only for the purpose above mentioned, but also in drawing.

(4) *A pair of dissecting-needles.* These may easily be made from two cedar-wood pen-holders by sawing them off through the metallic portion so that the remaining metal will form a ferule, and then, by means of pincers, forcing the heads of sewing-needles into the feruled ends. These needles are very useful for teasing apart tissues that have been treated with Schulze's maceration fluid.

(5) *A pair of sharp-pointed scissors* for dividing sections, membranous tissues, etc. Bent ones, such as those shown in Figure 3, are to be preferred.

(6) *A pair of delicate forceps or pincettes* for handling cover-glasses and small objects. A very good form for laboratory purposes is shown in the illustration (Fig. 3).

(7) *A supply of watch-glasses.* These are for containing sections during the processes of bleaching, staining, etc. The ordinary kinds of curved glasses, such as are readily procurable at

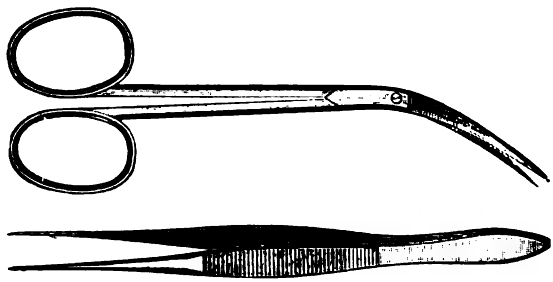


FIG. 3.—Curved Scissors and Forceps (Bausch & Lomb Optical Co.).

any watchmaker's, may be used, or, better, those made especially for microscopic purposes, and sold under the name of "Syracuse solid watch-glasses." These are usually sold in nests of six with a stand for holding them.

(8) *A small porcelain evaporating-dish* for use in macerating sections with Schulze's maceration fluid.

FIG. 4.—Capped Reagent-bottle.

(9) *One dozen capped reagent-bottles*, such as that shown in the illustration (Fig. 4), and three or four acid-bottles each of about one ounce capacity. The capped bottles should each be provided with a small glass tube or pipette.

(10) *A supply of camel's-hair brushes.* A half dozen, assorted sizes, are sufficient. They are useful in handling sections and in finishing slides.

(11) *A supply of glass slides* for mounting objects. They should be of regulation size, three inches by one inch, of clear, well-polished glass, have ground edges, and should not be too thick. Those about one millimetre in thickness are to be preferred.

(12) *A supply of thin cover-glasses.* Three-quarter-inch circles, No. 2, are suitable for most purposes, but it would be well

also to have a few of larger size, seven-eighths of an inch in diameter.

The following pieces of apparatus, though useful, are not really indispensable for such a course as here laid down:

(*a*) *A camera lucida* for drawing. The most useful form is that devised by Professor Abbé, and now manufactured under various modifications by most of the principal makers of microscopes. The principle of its construction is explained and illustrated in the author's *College Botany*, pp. 206, 207. There are several cheaper kinds, but this is altogether the most desirable.

(*b*) *A polariscope* is a useful adjunct to the microscope in the investigation of certain structures, as starches, crystals, thickened cell-walls, etc. It consists of two Nicol prisms, one usually screwed into the nose-piece just above the objective, and the other arranged to rotate beneath the stage.

FIG. 5.—Student's Microtome (Queen & Co.).

(*c*) *A pair of draughtsman's dividers* is a useful implement as an aid in drawing microscopic objects.

(*d*) *A microtome* for cutting thin and even sections of plant structures is useful, and for some of the more difficult investigations

where serial sections are required it is indispensable. For the latter purpose one of the numerous forms of the sledge microtome is probably on the whole the most desirable; but for the ordinary work of sectioning stems, roots, leaves, etc. the simple and inexpensive sectioner shown in Figure 5, and devised in accordance with the author's suggestions, is very convenient and efficient. It is a modification of the well microtome, the novel feature in which consists in the manner in which the object is clamped in the well so as to prevent it from bending or yielding before the knife. It is made of such a form as to be conveniently held in one hand while the knife is manipulated with the other. The accompanying illustration will give an idea of its appearance and the method of using it.

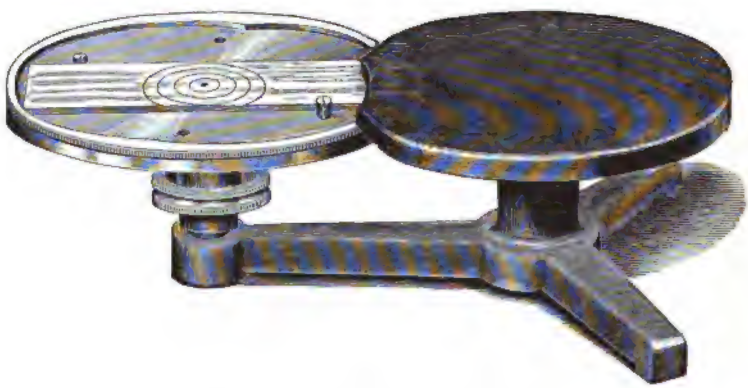


FIG. 6.—Centring Turn-table (Zentmayer).

(*e*) *A turn-table* is a very useful bit of apparatus for the permanent mounting, particularly the finishing, of slides. Some of the self-centring kinds are particularly convenient. One of these is shown in the accompanying illustration.

MICRO-REAGENTS.

Sulphuric Acid.—The strong acid dissolves starch and cellulose, causing them first to swell and then to disappear. It also produces chemical change in them, converting the former into dextrin and the latter into amyloid, a substance which, like starch, acquires a blue color with iodine. It dissolves protoplasm and other albuminous substances much more slowly, and hence may

be used for demonstrating the continuity of protoplasm from cell to cell in certain tissues. For this purpose it is used either strong or diluted with one-fourth its bulk of water. After acting for a few moments the acid is washed out thoroughly and the sections are stained.

Cuticularized and lignified tissues, if first treated with iodine solution and then with sulphuric acid to which one-fourth its bulk of water has been added, turn brown, but the former are not dissolved, and the latter are dissolved much more slowly than are cellulose tissues.

Cells containing protoplasm, if first treated with a solution of cane-sugar and then with dilute sulphuric acid, acquire a rose-red color.

In the dilute form sulphuric acid is also used as an aid to the identification of certain crystalline deposits in cells, crystals of calcium oxalate, calcium carbonate, calcium phosphate, and calcium malate being changed to needle-like crystals of calcium sulphate in the cells. Sphere crystals of inulin may also readily be distinguished from those of calcium phosphate by the fact that the former readily dissolve in sulphuric acid without residue.

Sulphurous Acid.—Certain objects when hardened in alcohol turn black, and sections become too opaque for study. To prevent this, Overton adds to the alcohol sulphurous acid and prepares the hardening solution as follows: He adds to half a gram of sodium sulphite a few cubic centimetres of 80 per cent. sulphuric acid, and conducts the fumes of sulphurous acid which are generated directly into 100 grams of alcohol. Sulphurous acid may be employed in the same manner in picric-acid hardening solutions.

A weak aqueous solution of sulphurous acid also greatly expedites the washing of tissues which have been hardened in chromic-acid solutions.

Hydrochloric Acid.—Besides its use in connection with phloroglucin, phenol, thymol, α-naphthol, and anilin chloride as a reagent for lignified tissue, hydrochloric acid is more or less useful as a clearing agent. It is also serviceable in distinguishing between calcium carbonate and calcium oxalate in cells, both being soluble in this reagent, but the former with effervescence, the latter more slowly and without effervescence.

A $\frac{1}{2}$ per cent. solution of hydrochloric acid in 70 per cent. alco-

hol is also serviceable in reducing the color of sections which have been over-stained in hæmatoxylin, carmine, and some aniline solutions.

Nitric Acid.—The strong acid immediately kills, but does not dissolve, protoplasm, and causes it to shrink away from the cell-wall. If a solution of ammonium or potassium hydrate be afterward added, the proteid cell-contents will assume a yellow color. This is called the xantho-proteid reaction for proteids.

If a section containing thick-walled tissues be treated first with hot nitric acid and then with ammonia, the middle lamella will be stained yellow.

A solution of 3 parts of strong nitric acid in 97 parts of water is sometimes employed for fixing protoplasm where it is desired to study the microsomes and other granular contents.

A 30 per cent. solution of nitric acid is used for the detection of amyloid, which at once swells strongly when the reagent is applied, and after a time completely dissolves.

Chromic acid is employed in .5 per cent. to 1 per cent. solutions for fixing the cell-contents of tissues. Tissues are soaked in it for twenty-four hours or more, and must then be washed thoroughly before staining, as the presence even of traces of the acid interferes with most stains.

A concentrated aqueous solution of chromic acid is often employed for the separation of cells, especially those of thick-walled tissues, since the middle lamella is more readily soluble in it than is the rest of the cell-wall. All cell-wall structures are, however, finally dissolved by it. Suberized and cutinized tissues, though, yield to its action only after a long time. Fungus cellulose also dissolves very slowly in it.

Acetic Acid (*Glacial*).—This acid in 1 or 2 per cent. aqueous solution is serviceable for defining the nucleus. It is also used for the same purpose in connection with certain stains, especially gentian-violet and methyl-green. In strong solution it is a valuable clearing agent, rendering the cell-contents more transparent and the cell-walls therefore more distinct.

A mixture of acetic acid 1 part and absolute alcohol 3 parts forms an excellent reagent for fixing cell-contents with the view to subsequent staining and study of the nuclear figures. This mixture is also useful in distinguishing between crystals of cal-

cium oxalate and those of calcium carbonate, the former being insoluble in it, while the latter dissolve with effervescence.

Formic acid is employed in much the same way as is acetic acid for the study of the nucleus and for clearing, and has about the same value.

Picric Acid.—Strong solutions, either aqueous or alcoholic, are employed for fixing the cell-contents. Objects should remain in the solution from twelve to twenty-four hours, and should then be washed thoroughly in alcohol before staining.

Picric acid is also used for the same purpose in association with sulphuric acid: 2 parts of the latter are mixed with 100 parts of water, and the mixture saturated with picric acid; the whole is then mixed with three times its volume of water. This solution has the advantage of being more readily washed out of the tissues by alcohol than that of picric acid alone.

By reason of its staining as well as its fixing properties picric acid is used also in association with carmine, nigrosin, and aniline-blue in the preparation of various structures for study.

Osmic Acid.—This poisonous substance owes its chief value in microscopy to the fact that it very rapidly penetrates tissues and instantly kills and fixes protoplasm. It is quite useful, therefore, in the study of nuclear figures. It is often employed for the purpose in 1 per cent. solution in distilled water. The treatment of the tissues with this reagent must be carried on in the dark, and the acid must be washed out thoroughly before exposing the tissues to the light, otherwise reduction to the metallic form will take place and the tissues will be blackened. This reduction always occurs when the acid, in contact with organic matter, is exposed to light. Tannins and fats also reduce osmic acid without the aid of light, and the acid may therefore aid in the detection of these substances.

Sections which have been blackened by osmic acid may be bleached, without injury to the structure, by means of hydrogen peroxide, which may be used in the proportion of 1 part to 10 or 15 of 75 per cent. alcohol. The sections may then be washed and stained.

Osmic acid is usually sold in sealed glass tubes containing 1 gram of the crystals. To prepare the solution the distilled water is measured out and poured into a suitable vessel, and then, by means of

pincers, the tube containing the acid is broken beneath the surface of the liquid. This is done to avoid danger of poisoning. The fumes should be respired as little as possible.

Phenol, or Carbolic Acid.—This is a useful clearing agent. For this purpose a 95 per cent. solution of the crystals in water is prepared, and the sections are allowed to stand in it for a time. The clearing is hastened by the application of heat. Specimens cleared in carbolic acid may be mounted directly in balsam, anhydration being unnecessary.

Carbolic acid is also used, in association with potassium chlorate and hydrochloric acid, as a test for lignified tissue, a blue or greenish-blue color being produced in lignified membranes by the reagent.

Potassium Hydrate.—This is one of the most useful of reagents. Its value depends, in the main, on its solvent effects upon proteid matters and starch, and on its power to cause cell-walls to swell, thus rendering their structure more evident. It is best obtained in sticks, and should be kept in tightly-stopped bottles until required for use, as on exposure it takes up carbon dioxide and water from the air and becomes converted into a solution of potassium carbonate. When a solution is required for use, remove a small piece from the bottle, dip it for a moment in water to remove the film of carbonate, and dissolve the remainder in a fresh portion of distilled water. For some purposes a dilute solution is to be preferred, for others a strong one. For the purpose of clearing tissues a 5 to 10 per cent. solution will usually suffice, and the best results are obtained by allowing the tissues to remain in the fluid for some hours. The sections should then be washed in clean water, and the remaining alkali be neutralized with dilute acetic acid before placing the sections under the microscope.

For the study of the markings on starch-grains only a very weak solution should be employed. The lamination of thickened cell-walls is often brought out very distinctly by soaking the sections for a few hours in a 5 per cent. solution of the alkali.

In concentrated solution potassium hydrate is one of the best reagents for the identification of suberized tissue, which is colored yellow by it. The color is deepened by gently heating, and if heated to boiling the suberin exudes from the cell-walls in the form of yellow drops.

Tannin may also be recognized by a strong solution of the reagent, the cell-contents of cells containing tannin turning yellowish or brownish. In dilute form potassium hydrate may also be used as a means of distinguishing between protein-crystals or crystalloids and crystals of inorganic matters. The former immediately swell and lose their angles, while the latter are mostly unaffected.

Very hard tissues, such as the shells of many nuts and the exterior coats of many seeds, may be softened for sectioning by soaking them for some time in solutions of this reagent. (For softening tissues by means of potassium hydrate, see Introduction to Part I.).

Potassium-iodide Iodine.—This is one of the most useful of the solutions employed in vegetable histology. It stains starch blue, proteid matters yellowish-brown, and lignified cell-walls a deep-brown. Along with sulphuric acid it may also be used as a test for cellulose, as follows: The sections are first treated with a few drops of the iodine solution, and then, after a few minutes, with a mixture of 2 parts of strong sulphuric acid and 1 part of water. After treatment with the acid the cellulose membranes, which are scarcely stained at all by the iodine alone, rapidly acquire a blue color, while the lignified cell-walls are stained a deep-brown. The iodine solution used for this purpose should consist of iodine 1 part, potassium iodide 4 parts, and distilled water 195 parts.

As a test for protoplasm it is better to use a stronger solution, in order that the staining effects may be decided, but as a test for starch the solution should be much weaker, otherwise the grains will be so deeply stained as to appear black. Iodine solution also rapidly kills protoplasm without dissolving it, and is therefore useful as a fixing agent. Vapor of iodine is sometimes employed for the same purpose.

All iodine solutions should be kept in amber-colored bottles to prevent the formation of iodic acid.

Chloriodide-of-zinc Iodine Solution.—According to Behrens, this solution may be prepared conveniently by dissolving 25 parts of pure zinc chloride and 8 parts of potassium iodide in 8.5 parts of distilled water and then adding as much iodine as will dissolve.

Solid chloriodide of zinc is, however, now an article of commerce, and a still simpler way of making the solution, according to Zimmermann, is to dissolve the salt in somewhat less than its

own weight of water, and then add a quantity of metallic iodine sufficient to give the solution a deep sherry-brown color.

This reagent is highly useful. It constitutes one of the best direct tests for cellulose, coloring it blue, while lignified and cutinized tissues are colored brown. Starch-grains are also stained blue by it, and, besides, are caused to swell and finally to disappear. It is useful in the study of sieve-tubes, since it stains callose a deep-reddish or reddish-brown color. It has, moreover, been employed with success in studying the continuity of protoplasm from cell to cell, since it swells the cell-walls and stains the protoplasmic threads brown.

Chloral-hydrate Iodine.—This consists of 5 parts of chloral hydrate dissolved in 2 parts of water to which a little iodine solution has been added. It is employed for dissolving chlorophyll bodies and to demonstrate the presence in them of minute starch-grains by causing the latter to swell and by staining them blue.

The solution without the iodine is also a useful clearing agent, especially for rendering leaves transparent after the chlorophyll has been dissolved out by alcohol.

Alcohol has many important uses in vegetable histology. One of the most important is for the preservation of tissues. For this purpose 70 per cent. alcohol is strong enough. But it is often desirable at the same time to harden the tissues preparatory to section-cutting. For this purpose strong alcohol, 95 to 98 per cent., is often necessary. If, however, the tissues are very delicate, they must not be placed immediately in alcohol of this strength, but must gradually be transferred through the medium of solutions of increasing strength, otherwise osmotic action will contract the tissues and render them unfit for study.

Alcohol dissolves chlorophyll and other coloring matters, together with resinous substances and some oils, and so acts as a bleaching agent.

Since it coagulates and kills protoplasm without seriously impairing its structure, alcohol is useful in preparing cells for the study of the cell-contents. Living protoplasm is so transparent as to be nearly invisible, and it is also very difficult to stain; but by treatment with alcohol protoplasm is rendered more opaque, and, besides, may then readily be stained with most of the usual staining fluids.

and alcohol is highly serviceable for the treatment of tissues which have been over-hardened in alcohol and rendered too brittle to be cut properly with the section knife. An immersion of twenty-four hours in the mixture will, if the specimens be not too large, usually suffice to put them in a condition fit for sectioning.

Glycerin is also employed to wash out the excess of anilin-blue in the study of sieve-plates.

Ammonio-ferric Alum.—A saturated solution of ammonio-ferric alum in distilled water constitutes a very convenient test for tannic matters, since it produces in the cells containing it a bluish-black or a greenish-black precipitate, according to the variety of tannin present. It should be remembered, however, that occasionally other substances, usually related to the tannins, may be present, which are capable of producing dark-colored precipitates with ferric salts. Instead of this, one may employ with equal advantage, when freshly prepared, the ferric-chloride solution described in the Introduction to Part I.

Fehling's Solution.—This is prepared as follows: Dissolve 34.64 grains of pure copper sulphate and 200 grains of Rochelle salt in the smallest possible quantity of distilled water. Also dissolve in 600 cubic centimetres of distilled water a quantitity of sodic hydrate sufficient to make a liquid having the specific gravity of 1.12. Keep the solutions separate in well-stopped bottles until required for use. When needed to test for sugar, mix 1 part of the former with 2 parts of the latter liquid, raise the mixture to the boiling-point, and dip the sections to be tested, for two or three seconds, in the hot liquid. If grape-sugar be present, the cell-contents will immediately be colored red by the precipitation of the suboxide of copper; if, instead, cane-sugar be present, a bluish or greenish color will be produced in the cells, but at first no red color. On soaking the section in the hot solution for a longer time a red precipitate gradually appears, because a part of the cane-sugar present is converted into invert-sugar. In performing this test it is better that the sections should not be very thin, both because of the inconvenience of handling thin sections and because of the facility with which the sugars escape from them into the hot solution.

Fehling's solution constitutes one of the best tests for sugar in tissues.

Labarraque's Solution (Solution of Chlorinated Soda).—This and the corresponding potash solution, called Javelle water, are useful clearing and bleaching agents where it is desired to study the cell-walls without the interference of the cell-contents. Sections placed in either solution should be watched carefully lest the destructive effects of the reagent extend to the cell-walls. If the sections are to be afterward stained, they must first be washed thoroughly to get rid of the last traces of the bleaching agent. The solutions, which are readily obtainable at most pharmacies, should be kept in a dark place and in tightly-stopped bottles. They require also to be frequently renewed.

Javelle Water (Solution of Chlorinated Potash).—Used for the same purposes as Labarraque's Solution (see above).

Chloral-hydrate Solution.—Used as a clearing agent. (See *Chloral-hydrate Iodine*, p. 264).

Diphenylamin Solution.—A good formula for the preparation of this reagent is that of Strasburger: Dissolve 0.5 grain of the crystals in 10 cubic centimetres of pure sulphuric acid. The solution is employed as a test for nitrates, tissues containing them turning blue on applying the reagent, from the formation of anilin-blue. The nitrites show the same reaction, but are very seldom found in plants.

Anilin or Anilin Oil.—This liquid is sometimes used as an intermedium between water and balsam, to obviate the necessity of complete anhydration by alcohol. Since anilin dissolves about four per cent. of water, the sections may immediately be transferred from aqueous liquids to anilin, and then from this to balsam. The anilin may be kept free from water by placing solid potassium hydrate in the containing vessel, the alkali possessing a strong affinity for water and being wholly insoluble in the anilin.

Potassium Bichromate.—A saturated solution of the salt in distilled water is often employed as a test for tannic matters, most tannins forming with it a yellowish-brown or dark-brown precipitate. Structures containing tannin may be placed *en masse* in the solution for twenty-four hours or more, and then be washed, sectioned, and examined. The masses, however, must not be of very large size, as the solution penetrates rather slowly. This reagent is not wholly satisfactory as a tannin test, since some other compounds besides the tannins form brownish precipitates with it.

In 1 or 2 per cent. aqueous solution the bichromate is sometimes employed in vegetable as it is in animal histology, as a hardening agent, though, on the whole, it is much less serviceable than alcohol.

Potassium Ferrocyanide.—A 10 per cent. aqueous solution has been employed successfully in connection with ferric chloride in staining proteids and in demonstrating the stratification in thickened cell-walls. For the former purpose, according to Zimmermann, the solution is prepared by dissolving 10 per cent. of the salt in a mixture of equal portions of water and acetic acid, specific gravity 1.063. The solution must be freshly prepared, as it readily spoils. In it the sections are soaked for a few hours, and then washed in 60 per cent. alcohol until the washing fluid no longer gives a blue color with ferric chloride; they are then treated with a dilute solution of ferric chloride, when, owing to the tenacity with which the proteid matters retain the ferrocyanide, they will be stained by the precipitation in them of Berlin blue, while the cell-walls will be scarcely, if at all, stained.

For the study of the cell-wall stratification the following plan may be pursued: Treat the sections, previously dried, in a 10 per cent. solution of the ferrocyanide, take up the superfluous liquid with blotting paper, and then immerse them for a few moments in a dilute solution of ferric chloride: Berlin blue will be precipitated in the strata, and more in those which are capable of taking up the most water, hence the strata will be seen more distinctly.

Silver Nitrate.—This is sometimes employed, in 2 or 3 per cent. solution in distilled water, for the study of the lamination in starch-grains and in thick-walled cells. The structures are first thoroughly dried at a temperature of about 60° C., and then treated with the solution for a few hours. After draining off the superfluous liquid and again drying, the structures are immersed in a .75 per cent. solution of common salt. This precipitates the silver chloride in the layers, and most abundantly in those which take up the solutions most copiously, so that after drying and exposure for a short time to strong light the laminæ or strata are brought out with great distinctness. The hilum in starch-grains is also rendered very conspicuous by this process.

Tannin Solution.—A 1 or 2 per cent. solution of tannin in distilled water is useful in connection with a very dilute solution of ferric chloride or of ferric alum in staining the walls of cells which

have been bleached by means of Labarraque's solution. The process is as follows: Thoroughly wash the sections after removing them from the bleaching solution, then soak them for a few minutes in the tannin solution, then, after quickly draining off as much as possible of the liquid, transfer them to the solution of ferric chloride. Even very thin membranes may then be seen readily, because stained a deep-black color. Tannin is also used in connection with osmic acid to stain crystalloids.

Sodium Phosphate.—A concentrated solution of the salt in distilled water is employed in the study of the crystalloids which are contained in protein-granules, as, for example, those in the endosperm-cells of the castor bean. The reagent dissolves all the rest of the grain, but leaves the crystalloid unchanged.

Cuprammonia.—This is prepared by adding to a strong aqueous solution of copper sulphate an aqueous solution of sodium hydrate, collecting the resulting precipitate by allowing it to settle, and then decanting the supernatant liquid. The precipitate is then dissolved in strong ammonia-water. This is the only known reagent capable of dissolving cellulose without producing chemical change in it. The reagent should be used in the undiluted form, and it is better when freshly prepared. It does not dissolve lignified cell-walls. The dissolved cellulose may be precipitated from solution by adding water.

Schulze's Maceration Mixture.—This consists of strong nitric acid in which chlorate of potash has been dissolved; it is chiefly used for the isolation of cells. Sections are placed in this mixture and gently heated until gases are evolved and the reddish color which first appears in the tissues has disappeared. The contents of the dish are then immediately poured into a large quantity of water to stop further action. The sections are now gently washed and stained with methyl-green. The cells may easily be separated by teasing or by mounting them in a drop of water on a slide and gently tapping the cover-glass with a needle-point.

The sections should never be transferred from alcohol directly to this mixture, but always from water; otherwise too violent, or even explosive, effects may be produced. It is better also to let the sections stand for a few minutes in the cold solution before applying heat, and then great care should be observed to stop the action at just the right point, otherwise either the middle lamella

will not be sufficiently dissolved to permit of the separation of the cells, or the tissues will be destroyed.

Since cutinized tissues resist much longer than any others the action of this liquid, it may be employed as a test for them. On boiling in the mixture for some time, however, the cells are disintegrated and converted into oily-looking drops of ceric acid.

Operations with Schulze's maceration mixture should be carried on under a fume-hood.

Phloroglucin Solution.—This is used in connection with hydrochloric acid as a reagent for lignified tissues, as already explained in the Introduction to Part I. It is, on the whole, the best reagent in use for lignified membranes.

Anilin Chloride.—A 5 per cent. alcoholic solution of this is employed in the same way as phloroglucin, along with hydrochloric acid, as a test for lignified tissues. It stains them a deep-yellow, while cellulose and cutinized tissues remain unstained.

Thymol Solution.—A 20 per cent. alcoholic solution is diluted with distilled water until the thymol begins to be precipitated, and an excess of potassium chlorate is then added. After standing for a few hours the solution is filtered, and it is then ready for use. It is employed in the same way as the phloroglucin reagent, with hydrochloric acid, as a reagent for lignified cell-walls, which it colors blue or bluish-green.

Instead of thymol, a strong solution of phenol, prepared by saturating it with potassium chlorate, may be employed in the same way and with similar results.

a-Naphthol Solution.—A 15 per cent. alcoholic solution is employed in the same way as phloroglucin, along with hydrochloric acid, for the identification of lignified membranes, which are stained blue-green by the reagent. With sulphuric acid the naphthol solution constitutes a test for glucose, levulose, and inulin. Sections to be tested are placed on a slide and treated first with the naphthol solution, and then a few drops of strong sulphuric acid are added, when, if either of the carbohydrates mentioned be present, a deep-violet color will soon appear.

Staining Fluids.

A very large number of staining fluids have been used in vegetable histology, but the following are the most important:

Grenacher's Alum Carmine.—A 2 per cent. solution of ammonia alum in distilled water is prepared, and to this is added a little powdered carmine; the mixture is boiled for twenty minutes so as to produce a deep-red solution, and is then cooled, filtered, and a small quantity of carbolic acid added to preserve it. It stains cellulose a bright-red color, lignified cells less readily, and cutinized cells not at all. When allowed to act for some time—say from twelve to twenty-four hours—upon cells containing protoplasm, the latter is stained, and the nucleus more strongly than the rest. The stain works best on tissues which have laid for some time in alcohol and have then been washed thoroughly in water. By a judicious use of the ½ per cent. solution of hydrochloric acid in 70 per cent. alcohol the stain may be washed out of the cell-walls and the protoplasm, remaining only in the nucleus. The solution thus becomes a valuable nuclear stain.

Ammonia Carmine.—Carmine is dissolved in strong ammonia-water until the latter is saturated. The solution is then evaporated over a water-bath to dryness, and the solid carminate of ammonia thus obtained is dissolved in distilled water in quantity sufficient to produce the requisite depth of color. This is preferable to the carmine solution above described for use with methyl-blue in the double staining of tissues, but is less useful as a nuclear stain.

Grenacher's Hæmatoxylin Solution.—A saturated solution of hæmatoxylin in absolute alcohol is prepared, and, in another vessel, one of ammonia alum in distilled water. The solutions are then mixed in the proportion of 2 parts of the former to 75 of the latter. The mixture is allowed to stand in the light for a week, is then filtered, and to every 7 parts of it 1 part each of glycerin and methylated alcohol are added. If, after standing for a time, a sediment is deposited, the mixture should again be filtered.

Hæmatoxylin solution stains both lignified and cellulose walls, but not cutinized ones. It is also an excellent nuclear stain. Old solutions are to be preferred, and the best results are obtained when the sections are soaked for some time in very dilute solutions. Alcoholic sections should first be washed thoroughly in water, and it must be borne in mind that the stain is not compatible with acids.

For nuclear stains the excess of stain should be washed out of

the cell-walls by means of the ½ per cent. solution of hydrochloric acid in 70 per cent. alcohol. To stop the action of the acid at the right point, it is best to replace the acid alcohol with some alcohol rendered slightly alkaline by ammonia-water. The sections may then be anhydrated and mounted in balsam.

Methyl-green Solution.—Dissolve enough methyl-green in distilled water to communicate to the liquid a deep-green color. This solution stains lignified and cutinized tissues more readily than those composed of pure cellulose. It also stains protoplasm and the nucleus. The tissues take up the stain more readily if they have previously been washed with water slightly acidulated with nitric acid.

Acetic methyl-green solution, which consists of a 1 or 2 per cent. solution of glacial acetic acid in distilled water in which methyl-green is dissolved until a clear blue-green solution is produced, is serviceable for fixing and staining the nucleus, but the color thus obtained cannot long be preserved.

Iodine-green Solution.—This solution consists of distilled water in which iodine-green is dissolved until the solution has a deep-green color. It stains lignified and cutinized tissues green, but cellulose tissues only slightly. It stains proteids, and is useful for staining the amyloplasts attached to young starch-grains. It is much employed, along with carmine, fuchsin, or eosin, for the double staining of tissues. In the latter process better results are obtained by using the stains successively than by mixing them.

Anilin-blue Solution.—The solution in water is sometimes employed, along with anilin-water safranin, to produce a double stain in tissues, the safranin going more to the lignified and cutinized tissues, and the blue to the cellulose tissues. Anilin-blue is useful in staining the callose of sieve-tubes. For this purpose it is best used very dilute, so that other structures will not be stained strongly by it. In case of over-stain, glycerin may be used to remove the excess, since this substance gradually removes the color from other structures, but leaves it in the sieve-plates.

Eosin Solution.—A strong aqueous or alcoholic solution is particularly useful in the study of sieve-tubes, since it stains the thin albuminous contents of these tubes a deeper red than the rest of the structure.

Dissolved in oil of cloves, eosin is used for clearing and at the

same time staining sections that have already been treated with anilin-water gentian-violet or iodine-green and afterward anhydrated with absolute alcohol. A fine double stain is thus produced. The violet or green remains in the lignified and cutinized tissues, while the cellulose walls are stained red by the eosin.

Fuchsin Solution.—A solution of fuchsin in water may be employed for staining lignified cell-walls, which hold the color more tenaciously than do unlignified ones, so that by washing the sections which have been stained in fuchsin with a solution consisting of 1 part of a saturated solution of picric acid in alcohol and 2 parts of distilled water the fuchsin is wholly removed from the unlignified cell-walls, while the lignified ones remain beautifully stained. The sections thus prepared may immediately be anhydrated and mounted in balsam, or they may first be double-stained by the use of anilin-blue.

Because fuchsin also stains cellulose tissues, it may be used with iodine-green or with methyl-green to produce double stains in which the fuchsin and the green go to the lignified and cutinized tissues, producing, in successful stains, a bluish-purple color, while the cellulose tissues will be colored by the fuchsin only. The most successful stains by this method are produced by using the greens first, washing the specimens, and then staining with the fuchsin.

Safranin Solution.—Anilin-water safranin is the best preparation for most purposes. It consists of equal parts by volume of anilin-water (prepared by saturating distilled water with anilin) and a concentrated alcoholic solution of safranin. When sections of stems, roots, etc. are immersed for a time in this solution and then washed with 70 per cent. alcohol rendered slightly acid with hydrochloric acid, the color is removed from the cellulose tissues, and if the process be stopped at the right point the cutinized and lignified tissues alone remain stained, and these of somewhat different colors. Safranin is a most successful nuclear stain if the sections be allowed to soak in it for a few hours and the excess of stain be washed out carefully with acid alcohol.

Gentian-violet Solution.—An excellent preparation is a mixture composed, by weight, of anilin 3 parts, gentian-violet 1 part, alcohol 15 parts, and distilled water 100 parts. Since, by means of alcohol, the solution washes out of cellulose tissues more readily

than from lignified and cutinized ones, it may be used to differentiate these tissues. If, after anhydrating the washed specimens, they be passed through oil of cloves in which eosin has been dissolved, beautiful double stains will be obtained.

By means of Gram's method most beautiful and instructive nuclear double stains are produced. The method is as follows: The sections are first soaked for about half an hour in the violet solution, and are then washed first with alcohol, then in a solution of potassium-iodide iodine (consisting of iodine 1 part, potassium iodide 2 parts, and water 300 parts), then again in alcohol until nearly all the color has been removed from the cell-walls; the sections are then passed through absolute alcohol and into eosin oil of cloves, and then, after a few minutes, they may be mounted in balsam. The chromatic nuclear figures will be stained violet, and the rest of the nucleus red.

Another solution of gentian-violet, particularly good for nuclear stains, consists of gentian-violet dissolved in 1 per cent. solution of acetic acid in distilled water until the liquid has acquired a deep-violet color.

Corallin Solution.—This useful stain is prepared as follows: Dissolve 3 grains of sodium carbonate in 2 ounces of distilled water, and in the solution thus obtained dissolve 10 grains of corallin, and filter. In order to preserve the liquid, place in the bottle containing it a few grains of camphor. Corallin thus prepared stains cellulose and lignified membranes different shades of red, sieve-callose a very brilliant red, and starch-grains red. The colors, however, are not permanent.

Picric-nigrosin Solution.—A good preparation is the following: To a saturated solution of picric acid in distilled water is added enough of a strong aqueous solution of nigrosin to give to the liquid a deep olive-green color. This solution fixes and at the same time stains the nucleus, and for this purpose is especially useful in the study of the filamentous algæ. Specimens usually require to be soaked in the solution for fully twenty-four hours in order to obtain satisfactory results.

Picric-nigrosin solution is also serviceable as a double stain for sections of roots, stems, etc., the nigrosin going to the cellulose and the picric acid to the lignified tissues. The preparations are permanent either in balsam or in glycerin jelly.

Cyanin Solution.—A solution of cyanin in equal parts of alcohol and distilled water is employed for the study of fats, which are colored a beautiful blue after soaking for half an hour or more in the solution. Glycerin or a strong solution of potassium hydrate may be employed for washing out the superfluous stain. The color is not permanent.

Alcannin Solution.—This stain is prepared by adding to the strong solution in absolute alcohol distilled water until a precipitate begins to be formed, and then filtering. It is used for the detection of fats, resins, and volatile oils, which after a little time it colors a deep-red.

The same solution may be employed for the identification of cutinized and suberized tissues, which after a few hours are colored decidedly by it, though not of so deep a red as are oily or resinous substances.

Great care should be exercised in the selection of the colors for staining, especially the coal-tar colors. Many of the safranins in the market, for example, are worthless for the purposes of vegetable histology. Only those colors should be purchased which are certified to by reliable dealers as suitable for microscopic use.

Permanent Mounting or Enclosing Media.

The most valuable are the following:

Canada Balsam, or Balsam of Fir.—This should be nearly colorless and entirely free from solid impurities. It may be kept in a capped bottle; but a better way is to obtain it in collapsible tubes of tin, which are now commonly sold by dealers in microscopical supplies. The ordinary or natural balsam, which consists of resin in solution in oil of turpentine, may be employed, or, as the writer prefers, the solution of the hardened resin in xylol.

Balsam mounts, though somewhat troublesome to make, are very durable and satisfactory.

Glycerin gelatin of good quality may be prepared as follows: Soak for an hour or more 1 ounce of the best French or German gelatin in 3 ounces of distilled water, and then raise the temperature nearly, but not quite, to the boiling-point, until the gelatin is completely dissolved; add 4 ounces of pure glycerin and as many drops of 95 per cent. carbolic acid, very gently stirring the

mixture with a glass rod, so as to mix thoroughly and at the same time to avoid air-bubbles, and then allow the mixture to cool. It soon sets and forms a clear, transparent jelly. If the gelatin used is of the finest quality and perfectly free from superficial dust (which may be ensured by rinsing rapidly in cold distilled water before using), filtering or straining will be unnecessary.

Carmine-stained preparations are unsuited to this medium, as the carmine is soluble in it. The same is true of several of the anilin stains (see Table). Hæmatoxylin-stained specimens keep well in glycerin gelatin, providing it contains no trace of acid.

Glycerin alone is often employed as a mounting medium, but is troublesome on account of the difficulty of enclosing it. For nearly all purposes glycerin gelatin answers as well, and it is far more convenient.

Processes of Mounting.

The process of enclosing in balsam may be outlined briefly as follows: First, the sections, if they have been stained in any aqueous medium, must be anhydrated, and this, especially if they be delicate, must be done gradually by transferring them first to weak alcohol, then to stronger, and so on through solutions of gradually increasing strength to absolute or at least 98 per cent. alcohol. The sections are then usually passed through a clearing medium such as oil of turpentine, oil of cloves, xylol, or oil of bergamot, and are then placed on the centre of the slide and immediately covered with a drop of balsam, on which is placed the cover-glass, care being taken to put it on in such a manner as not to entrap air-bubbles and to get it in the centre of the slide. If just the right quantity of balsam has been used, and none has oozed out around the edges of the cover-glass, nothing further is really necessary except to let the balsam harden; but some prefer to "finish" the slides, for appearance' sake, by ringing them. This is done by running a circle of cement around the edge of the cover-glass by means of a fine pointed brush and a turn-table. Of course, no colored or opaque cement that is soluble in balsam should be employed for this purpose, because sooner or later the cement would run under the cover-glass and spoil the specimen.

In cases where, for some reason, it is not desirable to pass the sections through alcohol, and yet it is of importance to mount them

in balsam, anhydration may be avoided by transferring them from the aqueous medium gradually to a concentrated solution of carbolic acid, and then immediately to balsam.

Instead of carbolic acid, anilin may be employed in the same way.

The process of mounting in glycerin gelatin is quite simple, but here also the effects of osmosis must be borne in mind. If the specimens are delicate, it will not do to transfer them at once from water or dilute alcohol to the enclosing medium. They must gradually be brought through weak into strong glycerin, and then be transferred to the glycerin gelatin. A very good way to accomplish the gradual transition is first to place the sections in 10 or 15 per cent. glycerin, and let this solution gradually concentrate by evaporation in a dry place protected from dust. The sections may then be transferred directly to the slide, the superfluous glycerin be taken up by blotting-paper, and a drop of the liquefied gelatin be placed upon them. The gelatin may readily be liquefied as occasion requires by placing the containing vessel in a dish partly filled with water and gradually applying heat.

It is advisable to use just enough of the medium to fill the space between the cover-glass and the slide. After the gelatin has set, it is desirable to protect the mount from injury by running a ring of some resinous cement—balsam, for example—around the edge of the cover-glass. After a long time the balsam is liable to crack. To prevent this the ring of balsam, after a few days, may be covered with one of gold-size. The mount is then almost as permanent as one in balsam.

Drawing Microscopic Objects.

What was said in the General Introduction about the importance of drawing is here repeated with emphasis. Every student who undertakes the work of the microscopical laboratory should by all means practise it. For this purpose he should, at the outset, provide himself with a suitable pencil and a drawing-book. Of course, drawings made by the aid of a good camera lucida, such as that described in the Appendix to Part II., *College Botany*, are likely to be somewhat more accurate than those made without its use, but the advantages of such an instrument are

likely to be over-estimated. In fact, dependence upon it tends to foster slavish copying, to the detriment not only of artistic skill, but to that of the observing faculties of the student. The student's first efforts at drawing should be undertaken without the aid of the camera, and he should begin with simple structures, such as single cells, starch-grains, etc., and after he has acquired some degree of skill proceed to more complex ones. The apparent dimensions of the object may readily be transferred to paper, either by means of a pair of dividers or by means of a graduated scale as suggested on page 254.

In using the camera lucida it is of importance that the drawing-paper and the field of the microscope should be nearly equally illuminated, otherwise the pencil-point and the object to be delineated cannot be seen with equal distinctness, and the outlines of the structure, therefore, cannot be followed with accuracy. The outlines should be traced with a fine-pointed, hard pencil such as Faber's or Hardtmuth's HHH. The tracing should be made on smooth-finished white paper or cardboard. The camera will seldom be used except to draw outlines and locate important points; to fill in the minute details by means of it is usually impracticable.

Drawings designed merely as a record of observations or for the wood-engraver may be left in lead-pencil, but those that are to be reproduced by photographic process should be drawn in the blackest of black ink.

General Directions for Work.

(1) The student should at the very outset thoroughly acquaint himself with the mechanism of the microscope and the accessory apparatus with which he has to work, that he may use them intelligently.

(2) He should observe great care in the removal and putting on of objectives, so as not to drop them. Eye-pieces and micrometer should also be handled with especial care.

(3) He should observe care in focusing, particularly with high powers, so as not to run the objective down against the slide, and thus endanger breaking either the cover-glass or the objective. He should take care also that the object is in accurate focus, otherwise it cannot be seen distinctly.

(4) He should give due attention to the adjustment of the reflecting mirror, so as to secure the most perfect illumination of the object. Much of his success in seeing will depend upon the care with which this is done.

(5) He should bear in mind that many of the reagents employed are corrosive, and be correspondingly careful in the use of them. Some of the acids are volatile, which is a reason for keeping the containing bottles stopped when not in actual use; all the acids and iodine will act on brass-work; potassium hydrate will corrode glass; Schulze's maceration fluid evolves very corrosive fumes, which should not be permitted to escape into the room; and even alcohol and alcoholic solutions will remove the lacquer from the brass-work of the microscope.

(6) Nearly all objects to be examined will be studied as transparent objects—that is, they will be studied by transmitted light—and they will therefore be mounted in liquid of some kind, and should always be covered with a cover-glass, not only to avoid the distortion of the image which a curved or uneven liquid surface inevitably produces, but to protect the objective. Before placing the mounted object on the stand all liquid that oozes from under the edges of the cover-glass should be wiped away.

(7) Cleanliness should characterize all the work of the microscopical laboratory. All apparatus, slides, cover-glasses, etc. should be kept scrupulously free from dirt. The glasses of the objectives and the eye-pieces should never be touched with the fingers, for that would soil them and impair their optical performance. Whenever they need cleaning, which should not be often, the glasses should be breathed upon and be wiped gently either with a piece of perfectly clean and soft linen cloth or with a piece of the thin, soft paper that is sold at dental supply stores under the name of "Japanese filter-paper." A convenient way is to keep always at hand, in a place secure from dust, a quantity of this paper cut into suitable sizes. It is useful also for cleaning cover-glasses, slides, etc. If a fresh piece be used each time, there will be little danger that the glass of an objective or an eye-piece will be scratched or marred or its polish dimmed. All bottles containing reagents and stains should be kept stopped to prevent evaporation and the entrance of dust when not in actual use; the glass tubes used in applying the tests should always be returned imme-

diately to the proper bottles. Care ought also to be exercised not to put the caps on the wrong bottles.

(8) It is very important that the razor or section knife for cutting sections be always keen-edged, and the student should provide himself with the necessary appliances for sharpening. For most purposes sections require to be cut quite thin. The knife should be given an oblique or sliding motion in cutting, and should be pushed rather than drawn through the object. The motion should be steady and even, and never a to-and-fro or sawing motion. The forefinger of the hand holding the object should be extended slightly, so as to form a rest for the razor-blade as well as to assist in starting the section of the right thickness. Quite hard tissues may be cut successfully if only very thin sections of them are attempted, but if the knife-edge is allowed to run deep it is liable to be notched. Portions of thin structures, such as leaves, petals, and stamens, may readily be sectioned by placing them between pieces of elder or sunflower pith and cutting through pith and all. In case the tissue to be cut is quite hard, cork may often advantageously be substituted for the pith. Longitudinal sections of such small objects as ovules may often successfully be made by putting them between flat pieces of cork or pith and running the knife-blade vertically through them between the pieces of supporting material.

The knife should always be cleaned carefully after using it, and pieces of tissue should never be allowed to dry upon it, otherwise its surface will soon become tarnished by the acids and tannins in the tissues, and sections will not so readily slide up on the blade, but will fold or crumple.

In most instances it is best in cutting to keep the knife-blade wet with alcohol or with a mixture of equal parts of alcohol and glycerin. Sections of fresh tissues or of those that have been kept in any of the preservative fluids should, immediately after cutting, be transferred—best by means of a camel's-hair brush—to liquid, otherwise air will get into the cells and seriously impair the value of the section for study.

(9) The student should, in all his work with the microscope, proceed understandingly, endeavoring to know the reason for every test he is directed to apply, and carefully interpreting the results of each test.

(10) It is excellent practice for the student to keep an accurate record, both in writing and by means of drawings, of the work done and the facts observed in the laboratory.

The following table gives a bird's-eye view of the different reagents and stains, their composition, and their most important uses. The student will find it convenient for reference.

	Amyloid.	Amyloplasts.	Callose.	Cellulose.	Chloroplasts.	Clearing.	Crystalloids.	Cutin or Suberin.	Fats.	Fixing.	Hardening.
Acid, acetic.				38% swells and defines.						With alcohol.	
Acid, carbolic.						Clears cells.					
Acid, chromic				25% dissolves.						1% solution.	1% solution.
Acid, formic.											
Acid, hydrochloric.				Swells.							
Acid, nitric.	Swells and dissolves with 30%									Fixes protoplasm.	
Acid, osmic, 1%.							Renders distinct and slowly stains.		Colors brownish-black.	Fixes protoplasm.	
Acid, picric.										Fixes proteids.	
Acid, sulphuric.				Strong rapidly dissolves.				Strong dissolves very slowly.			
Acid, sulphurous.						Decolorizes.					
Alcannin (in 50% alcohol).								Stains slowly red.	Stains bright red.		
Alcohol.					Dissolves out chlorophyll.				Dissolves castor and croton oils.	Fixes protoplasm and nucleus	Hardens by withdrawing water.
Alum, ammonio-ferric.											
Alum carmine, Grenacher's.				Stains red.							
Ammonia carmine.				Stains red.							
Anilin-blue.			Stains blue.	Stains blue.							
Anilin chloride.											

Lignin.	Middle lamella.	Mounting medium.	Nitrates.	Nucleus.	Proteids.	Resins.	Starch.	Sugar.	Swelling.	Tannin.	Form in which used.
38% swells and defines.				1% defines.	With alcohol fixes.						Solution in water or alcohol.
Green or blue-green with HCl.											Mostly strong solution in water.
25% dissolves slowly.	25% dissolves readily.			1% fixes and stains brown.	1% fixes.						Solution in water.
				1% defines.							In water or with methyl-green.
					Disorganizes.		Swells.				Usually strong.
	Yellow with ammonia.				Yellow with ammonia.		Dissolves.				Usually strong.
				Fixes.	Fixes.					Stains bluish or brownish.	In ½% or 1% aqueous solution.
Stains yellow.				Fixes.	Fixes.						In saturated aqueous or alcoholic solution.
Strong dissolves slowly.					Strong dissolves slowly.		Dissolves.				The pure acid or mixed with one-third water.
											Mostly dilute in alcohol.
						Stains bright red.					Sol. in alcohol diluted with water to 50%.
				Fixes.	Fixes.	Dissolves.					Absolute for anhydrating.
										Greenish-black or bluish-black precipitate.	Concentrated solution in water.
		Balsam.		Stains nucleus red.	Stains red.						See formula.
		Balsam.		Stains red.	Stains red.						See formula.
		Balsam and glycerin.			Stains blue.						Aqueous solution.
Colors yellow.											5% alcoholic sol. first, then strong HCl.

TABLE OF REAGENTS

	Amyloid.	Amyloplasts.	Callose.	Cellulose.	Chloroplasts.	Clearing.	Crystalloids.	Cutin or Suberin.	Fats.	Fixing.	Hardening.
Anilin oil.											
Bergamot oil.						Before mounting in balsam.					
Chloral hydrate.					Swells and dissolves.	For clearing.					
Clove oil.						Before mounting in balsam.					
Cuprammonia.				Dissolves cellulose.							
Cyanin.								Stains blue.	Stains blue.		
Diphenylamin.											
Eosin.				In clove oil sol. red.							
Ether, sulphuric.									Dissolves.		
Fehling's solution.											
Fuchsin.		Red with acid fuchsin.		Red.							
Gentian-violet.				Violet. Washes out.							
Glycerin.											
Hæmatoxylin, Grenacher's.				Violet.							
Iodine, chloral-hydrate.					Swells and destroys.						
Iodine-green.								Blue-green.			
Iodine, potassium-iodide.					Brown.						
Iodine, zinc-chloriodide.				Swells. Blue.							
Javelle water.				Bleaches.							
Labarraque's solution.				Bleaches.							
Mercuric chloride.										Renders proteids insol.	

AND STAINS (CONTINUED).

Lignin.	Middle lamella.	Mounting medium.	Nitrates.	Nucleus.	Proteids.	Resins.	Starch.	Sugar.	Swelling.	Tannin.	Form in which used.
											Used for anhydrating in balsam mounting.
											Undiluted.
					Swells and dissolves.						Strong aqueous solution.
											Undiluted.
											Undiluted.
Stains blue.											Solution in 50% alcohol
			Blue color with.								Sol. of 0.5 gms. in 10 cc. of H_2SO_4.
In clove oil sol. red.		Balsam.			Red.						Used in aq. sol. for study of sieve-tubes.
						Dissolves.					Undiluted.
								Red precipitate with glucose.			See formula.
Red.		Balsam and glycerin.			Red.						Aqueous solution.
Violet.		Balsam.		Violet.							Anilin-water solution.
											Mainly as mounting medium.
Violet.		Balsam and glycerin.									See formula.
Stains brown.					Swells and destroys.		Swells and stains blue.				See formula.
Green.		Balsam and glycerin.									Aqueous solution.
Brown.					Brown.		Blue.				See formula.
Swells. Brown					Brown.		Blue. Swells and dissolves.				See formula.
Bleaches.					Destroys.					Destroys.	Usually diluted.
Bleaches.					Destroys.					Destroys.	Usually diluted.
				Fixes.	Fixes.						Alcoholic or aqueous solution.

	Amyloid.	Amyloplasts.	Callose.	Cellulose.	Chloroplasts.	Clearing.	Crystalloids.	Cutin or Suberin.	Fats.	Fixing.	Hardening.
Methyl-green.								Green.			
Methyl-green (acetic).								Green.			
Millon's reagent.				Swells.							
α-naphthol (15% sol.).											
Phloroglucin reagent.											
Picric nigrosin.				Greenish.						Protoplasm and nucleus	
Potassium bichromate.											1% or 2% solution.
Potassium ferrocyanide.				Blue with sol. of ferric chlor.							
Potassium hydrate.				Swells.		Dissolves proteids and starch.		Strong and hot. Yellow.	Saponifies. Fatty acids crystallize.		
Safranin.				Red easily washed out.				Deep red.			
Schulze's maceration mixture.				Destroys when hot rather rapidly.				Destroys very slowly. Before KHO yellow.			
Silver nitrate.											
Sodium phosphate.							Insoluble in.				
Tannin.				Black with ferric chlor.			Brown before osmic acid.				
Thymol.											

AND STAINS (CONTINUED).

Lignin.	Middle lamella.	Mounting medium.	Nitrates.	Nucleus.	Proteids.	Resins.	Starch.	Sugar.	Swelling.	Tannin.	Form in which used.
Green.			Balsam and glycerin.		Green.						Aqueous solution.
Green.		Not permanent in balsam or glycerin.		Green.	Green.						Used as nuclear stain.
Swells.					Reddens and disorganizes.		Swells.				Solution must often be renewed.
With HCl blue-green.								Violet with H_2SO_4.			
Red with HCl.											5% alcoholic solution and HCl.
Yellow.		Balsam and glycerin.		Blue-green.							See formula.
										Brownish precipitate.	For tannin strong solution in water.
Blue with sol. of ferric chlor.											Used for study of cell-walls.
	Strong and hot. Dissolves.				Destroys.		Destroys.			Strong. Yellowish or brownish.	In aqueous solution mostly.
Deep red.		Balsam.		Red.	Red.						See formula.
Destroys when hot rather rapidly.	Dissolves readily.										HNO_3 with $KClO_3$ in solution.
		Balsam.					Shows strata in.				Used in 5% aqueous solution for study of starch.
					Dissolves, except crystalloids.						Strong aqueous solution.
Black with ferric chlor.											With Fe_2Cl_6 for study of thin membranes.
Green or blue-green with HCl.								Red before H_2SO_4.			See formula.

EXERCISE I.

THE TYPICAL VEGETABLE CELL.

SELECTIONS for study may be made from among the following objects: the colorless epidermis of one of the fleshy scales of an Onion, Lily, Hyacinth, or Amaryllis bulb; the leaves of some of the mosses and liverworts, as, for example, those of Bryum roseum, *Schreb.*, Mnium cuspidatum, *Hedw.*, Jubula Hutchinsiæ, *Dumort.*, and Jungermannia Schraderi, *Martius;* or the filaments of some of the filamentous algæ, as Cladophora glomerata, *Kützing*, Œdogonium princeps, *Wittr.*, Spirogyra crassa, *Kützing*, or Zygnema insigne, *Kützing*.

For the present study selection is made of the epidermis of one of the fleshy scales of the Onion (Allium Cepa, *L.*), preferably that from the dorsal or convex surface of the scale.

(1) With the razor cut through the epidermis, but as little as possible into the sublying tissues, and, seizing the epidermis between the thumb and the razor-edge, strip it off and immediately transfer it to a slide previously wet with a drop of water; flatten it out with a camel's-hair brush, by means of the scissors or a knife-blade trim away those portions of it which have some of the sublying tissue attached, and cover the remainder with a cover-glass. In doing this be sure there is enough water on the specimen completely to fill the space between the cover-glass and the slide. The cover-glass—which, to prevent soiling, should be handled with the pincettes, and not with the fingers—should be brought down on the specimen one edge first or at a considerable angle with the slide, and then should gradually be pressed down into position. This is for the purpose of driving out the air. Air-bubbles seriously interfere with the view of the structure, and in all mounting, whether temporary or permanent, must carefully be avoided. Care should be taken also to place the object and the cover-glass as near the centre of the slide as possible.

(2) The slide is now placed on the stage of the microscope, with the object over the centre of the stage aperture, and is brought into the focus of a low-power—say the two-third-inch—objective. Where a double or triple nose-piece is employed it is best always to focus upon the object with the low power, and then afterward, if necessary, with a higher one, as the objective and the nose-piece are so arranged, or should be, that when the object is in the focus of the low power, by simply rotating the nose-piece and bringing the high-power objective into position the object will be very nearly in the focus of this also. This makes focusing with the high power easy, and avoids the danger of running the objective down on the cover-glass. In focusing with the low power it is also good practice, before looking into the tube, to rack the objective down to within about a quarter of an inch of the object, and then, while looking through the tube, rack it up again until the object appears in distinct focus. Before focusing, the mirror should be so adjusted that the field appears brightly illuminated; then, after focusing, it will probably need to be adjusted still further in order to obtain the best illumination. The direct sunlight should never be employed for the purpose, but diffused light from the sky or, better still, if it can be obtained, from a white cloud. If lamplight be employed, it is well to correct the unpleasant yellow of the rays by passing them through glass faintly tinged with blue.

(3) Examining now the object, there will be observed a rather fine and somewhat irregular network, or what seems to be such. What is really seen is an aggregation of closed sacs, each a cell, placed together in a single layer and in such a way that there are no spaces between them. The cell-walls are so nearly transparent that it is only at their edges where they join or merge into a common wall between two cells that one is able to see them without staining. In the interior of the cells there may be seen, with care, more or less of minutely granular matter, and possibly very faintly a larger rounded mass, the nucleus, but otherwise the interior appears perfectly transparent. These sacs, however, are by no means empty, nor are they filled with air or other gaseous matter; as will presently be shown, they are filled with a liquid or semi-liquid matter which is invisible only because it is colorless and has nearly the same refractive index as has water.

Without changing the focus, let now the high power be turned on (the one-sixth or one-eighth-inch objective), and, by means of the fine adjustment, let the cells be brought into accurate focus. Fewer cells will now be seen in a single view, but these cells will appear very much larger, and the granular cell-contents as well as the cell-walls will be much more distinctly visible. Not all the parts of a cell, however, can be seen at once, for only a narrow space measured in a vertical direction can be in focus at the same time; to explore the whole cell it is necessary to focus up and down by means of the fine adjustment. The nucleus may or may not be distinctly visible. If visible, it is usually but faintly so, by reason of its transparency.

(4) Reversing the nose-piece now, and bringing the low power into position so that the instrument will be ready for the next step in the study, the slide is removed from the stage, the cover-glass is taken off, two or three drops of the strong solution of potassium-iodide iodine are dropped on the specimen, and, after allowing the liquid a few minutes to penetrate, the cover-glass is put on as before; any of the reagent that oozes out around the edges of the cover is now soaked up by means of blotting paper, and the slide is replaced on the stage of the microscope. Focusing upon the cells now, it is observed that the cell-walls have scarcely been stained at all, but the protoplasm and nucleus are rendered distinctly visible by reason of the yellowish-brown color they have acquired. Iodine thus constitutes one of the tests by means of which are recognized protoplasm and other proteid matters, all of which are stained yellowish-brown by it.

It is observed also that the protoplasm is not equally distributed through the cell, and that the nucleus sometimes occurs in the centre, sometimes lodged against the wall of the cell, and sometimes even there are two nuclei in a cell. Studying these phenomena more particularly with the high power, it is observed that next the cell-wall and usually closely applied to it, but sometimes slightly pulled away from it by the osmotic action of the test-liquid, is a continuous layer of protoplasm, forming a kind of inner cell-wall. This is the *primordial utricle*, which is really made up of an outer, less granular layer called the *ectoplasm*, and an inner, more granular one called the *endoplasm*, though it is not easy, except with the most careful staining and the

best light, to distinguish these layers even with the highest powers.

Interior to the primordial utricle are seen irregular threads and bands of granular protoplasm connected with the endoplasm on the one hand and with the nucleus on the other. The spaces between these threads and bands are sap-cavities or *vacuoles*. The nucleus usually appears as a rounded, oblong, or sometimes fusiform mass, of denser texture than the rest of the protoplasm, and bounded off from it quite sharply, though always in contact with it. The nucleus is, in fact, enveloped in a very delicate membrane. In the interior of the nucleus are visible one, two, or sometimes more rounded spots, of different density from the rest, called the *nucleoli*.

(5) But there is yet to be learned the nature of the cell-wall. Is it composed of cellulose, is it lignified, or is it cutinized? Endeavor is made to answer the question by means of an experiment. Again reversing the nose-piece so as to bring the low power into position, there is placed at the edge of the cover-glass, care being taken not to get any on the upper side, a single drop of a mixture consisting of strong sulphuric acid 2 parts and water 1 part, and the mixture is permitted to run under by capillary attraction and to come into contact with the iodine-stained section. The effects are now observed under the microscope. The walls of the cells affected begin to assume a deep-blue color, owing to the conversion, by the acid, of the wall-substance into a starch-like compound called *amyloid*, which is immediately stained blue by the iodine present. This change of color is accompanied by a decided swelling, which continues until the cell-wall is dissolved and the color at first produced disappears. Not all of the wall, however, is colored blue, nor is all dissolved. A light line will be observed bounding off the cells from each other, and this line increases in size as the action continues. This middle portion of the cell-wall is a little different from the rest in chemical composition, and dissolves more readily. But after this and the portion stained blue have wholly disappeared there remains a thin pellicle which is stained a deep-brown color. This is really the outer portion of the walls of the cells, the cuticle of the epidermis. There are, then, in the cell-wall three substances, chemically different: the part that stains blue with

iodine and sulphuric acid, called *cellulose;* a part that readily dissolves, but does not stain—the middle lamella, composed chiefly of insoluble pectates; and the cuticle, which is chiefly composed of a substance different from either, called cutin.

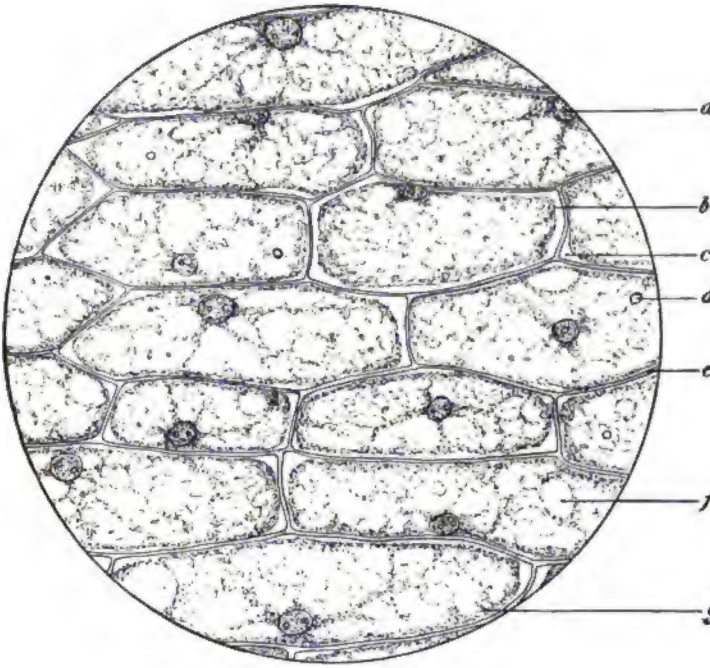
Another fact observed is that the protoplasm has been stained even a deeper brown than before, and that it is still recognizable, though disorganized, after the cellulose has disappeared.

Another reagent, even better for the recognition of cellulose and for distinguishing between it and cutin, is chloriodide-of-zinc iodine. Let there be mounted a fresh portion of the epidermis of the Onion scale in a few drops of this liquid, taking care not to dilute the latter, and permitting a few minutes to elapse before putting on the cover-glass, so as to give the reagent opportunity thoroughly to penetrate the cells. As before, it is found that the walls are stained blue, but less intensely, and, though swollen, they are not dissolved. The cutinized portion of the cell-wall is also turned brown, but this is best seen by studying a transverse section.

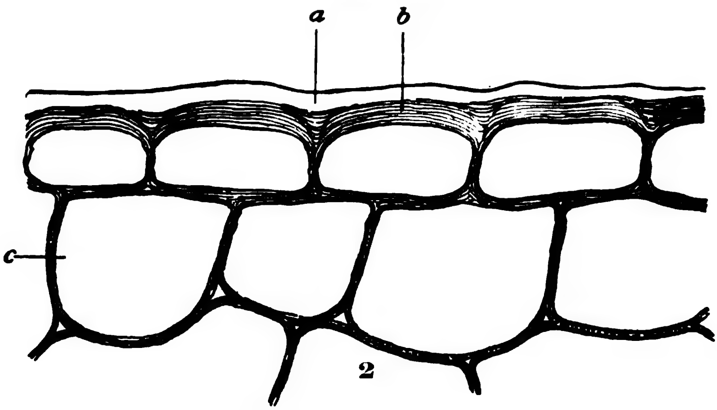
Sections may best be made by cutting through two or three scales at once. Placing one or two of these sections on the slide, treating them with a few drops of the reagent, and examining them with the high power, it will be found that the cells appear in a shape very different from that observed in the other view. They are oblong or nearly rectangular, with the longest diameter parallel to the surface of the scale; the inner and radial walls are thin, but the outer wall is thickened, and it is the exterior part of this wall that has acquired the brown color; it is the cutinized part, or cuticle.

(6) Beautiful and instructive permanent mounts may be obtained by the following method: First, let there be stripped off portions of the epidermis, and, to prevent them from curling, let them be spread out rapidly on slides and afterward treated with alcohol to kill and fix the protoplasm. They are then thoroughly washed in water and placed in Grenacher's alum-carmine, in which they are allowed to remain for twenty-four hours. They are then removed from the staining fluid, rinsed, and passed through weak, strong, and finally through absolute alcohol, then placed for a few moments in oil of cloves, and from this transferred to the centre of a slide, a drop of xylol balsam placed on them, and the cover put on,

care being taken in doing so not to entrap air-bubbles. The cell-walls will be stained red, but will be sufficiently transparent to allow the nucleus and the protoplasm, also stained red, to be seen distinctly. It is from specimens thus treated that the accompanying drawings (Pl. XXXVIII.) have been made.



1



2

PLATE XXXVIII., FIG. 1.—Cells of Outer Epidermis of Onion-scale (magnified 200 diameters): *a*, nucleus; *b*, primordial utricle shrunken away from the cell-wall somewhat by the action of the alcohol; *c*, space between cell-wall and primordial utricle; *d*, an oil-globule, which may best be seen in an iodine-stained section; *e*, cell-wall; *f*, vacuole; g, granular protoplasm.

FIG. 2.—Transverse Section of Epidermis of Onion-scale, showing thickening of exterior wall and cutinization of its outside portion. The unshaded part. *a*, represents cuticle; the shaded parts, *b*, the cellulose portion of the wall; *c*, one of the parenchyma-cells beneath the epidermis. The walls are considerably swollen, the drawing having been made from a section that had been treated with zinc-chloriodide iodine. The cell-contents are omitted from the drawing. (Magnification, 285 diameters.)

EXERCISE II.

TISSUES OF THE HIGHER PLANTS.

SECTIONS of the stems of almost any fern, gymnosperm, monocotyl, or dicotyl will afford instructive study, for in all these plants are found, not one kind of cell merely, as in the filamentous algæ, for example, but many kinds, differing from each other not only in shape and in size, but also in structure and in function. These different kinds of cells are called *tissues*. The cells of the Onion epidermis already studied really constitute a tissue, but they are only slightly modified from the primitive cell-type. Many of the other tissues are, however, strongly modified —so strongly, in fact, that they have largely lost their cellular character, and at maturity serve merely a mechanical purpose in the plant. There is every gradation between these two extremes. The different kinds of tissues are fully described and illustrated, and their relations explained, in Part II. of the author's *College Botany*, to which the student is referred; but here is repeated only the scheme of classification that will serve as a guide in the practical studies to follow:

TISSUES.

- I. *Parenchymatous series.*
  - 1. Parenchyma, ordinary soft cellular tissue.
  - 2. Collenchyma, or thick-angled tissue.
  - 3. Sclerotic parenchyma, or stony tissue.
  - 4. Epidermal or boundary tissue.
  - 5. Endodermal tissue.
  - 6. Suberous or corky tissue.
- II. *Prosenchymatous series.*
  - 7. Wood, or libriform tissue.
  - 8. Tracheids, or vasiform cells.
  - 9. Ducts, or vascular tissues:
    - *a.* Dotted ducts; *d.* Annular ducts;
    - *b.* Scalariform ducts; *e.* Reticulate ducts;
    - *c.* Spiral ducts; *f.* Trabecular ducts.
  - 10. Hard bast or bast-fibres.
- III. *Sieve series*, including only—
  - 11. Sieve or cribriform tissue.
- IV. *Laticiferous series*, including—
  - 12. Laticiferous or milk-tissues, of which there are two varieties:
    - *a.* Simple, and
    - *b.* Complex.

Of the above tissues, all of the prosenchymatous series are at maturity destitute of living protoplasm, and are therefore mechanical in their function; so also are sclerotic and suberous tissues; and collenchyma and endodermal tissues are partly so. The stems, leaves, and roots of almost any of the higher plants contain several of these tissues, sometimes nearly all of them, but a few are of rare occurrence.

For the purpose of getting a general idea of the commonest and most important, let sections, transverse and longitudinal, of the stem of the common Geranium (Pelargonium zonale, *Willd.*) be studied.

I. TRANSVERSE SECTION.—Having made a section, as thin as possible, extending from the outside to and into the central pith, it is placed on a slide and treated with a few drops of the zinc-chloriodide iodine, and after a few minutes examined under the low power.

It is observed, first, that there are tissues whose cell-walls have stained blue, and others whose cell-walls have stained a deep-brown. It is observed also that there are great differences of size and shape among the cells, differences in the compactness of their arrangement, and differences in the thickness of their walls, as well as great differences in their contents.

(1) On the very outside may be found a single tier of closely-laid and similar cells interspersed with hairs and having their outer walls thickened. This is the epidermis. Beneath it, if the stem is not too young, are several tiers of tabular or brick-shaped cells arranged in radial rows. The members of the outer tiers are empty, or at least contain no protoplasm, and their walls are stained brown. The inner members of the series, which are younger, may still contain protoplasm, and the walls may show some blue color. This whole series of tabular cells constitutes the cork-tissue which has formed underneath the epidermis, and which sooner or later, by the continuous multiplication of its cells, will push the epidermis off, and afterward the cork-cells themselves will peel off at the surface. It is this peeling off which gives the rough appearance to the exterior of the stem when it is old. Destruction of the epidermal and exterior cork-cells had in fact begun in the specimen from which the drawing (Pl. XXXIX.) was made. Figure 1, *a* represents the corky tissue.

(2) Underneath the cork is seen a tissue composed of cells quite different in shape and arrangement from the cork-cells. They are rounded or somewhat polygonal in outline; their walls are not cutinized, but are of cellulose, and therefore stain blue instead of brown with the zinc-chloriodide iodine reagent; they are not arranged in radial rows; they have more or less conspicuous thickenings at the angles where they join other cells; and they are rich in proteid contents. This is collenchyma-tissue, represented at *b* in Figure 1 (Pl. XXXIX.).

(3) Still further interior is found a much greater thickness of cells, different from the rest. They are larger than the collenchyma-cells; they are not thickened at the angles, but have small angular interspaces instead; their walls are thin and composed of cellulose; and they are rich in proteid and starchy contents. This is parenchyma-tissue, represented at *c* in Figure 1 (Pl. XXXIX.).

(4) Interior to this again is a zone of much smaller, angular, and very thick-walled cells whose walls have stained a deep-brown. The cells of this tissue are destitute of proteid and starchy contents; they are also very compactly arranged, so that there are either no intercellular spaces or only very minute ones. These thick-walled cells are bast-fibres constituting a variety of the mechanical tissues, and their walls, like those of most other mechanical tissues, are lignified. With the reagent that has been employed they have been stained the same color as the cork-cells, but their chemical constitution is not the same, as may readily be proved by means of another test: Let a fresh section of the same stem be treated first with two or three drops of the phloroglucin solution, and after a few moments with a similar quantity of hydrochloric acid; the section is then covered and examined: the bast-fibres are now found to be stained red, while the cork-cells remain unchanged in color. The bast-fibres are shown at *d* in Figure 1 (Pl. XXXIX.).

(5) Next the bast-fibres, on the side toward the pith, is a not very broad area or zone of small-celled tissue whose walls have stained blue with the chloriodide. By turning on a higher magnifying power there can easily be distinguished in it two layers: the outer layer, composed of somewhat larger cells which in this view appear more rounded, of unequal size, and which are not arranged in any apparent order, constitutes the soft bast, made up chiefly

of two kinds of thin-walled tissues—sieve-tissue and a variety of parenchyma; the inner of the two layers is composed of very minute and very thin-walled cells, rich in protoplasm, but destitute of intercellular spaces, and the cells have a more or less evident arrangement in radial rows. This is called meristem-tissue, and the zone of it which occurs here at the junction of the wood and the bark constitutes what is called the cambium zone of the stem. Meristem-tissue is, however, not really a separate tissue, but consists of very young cells, some destined to develop into one kind of tissue, others into another. In the illustration *e* and *f* (Fig. 1, Pl. XXXIX.) are respectively the soft bast and the meristem-tissues.

(6) Next interior to the cambium zone is a tissue-layer, more or less broad according to the age of the stem, composed of cells the majority of which, in this view, look like bast-fibres and have stained the same color. Sprinkled among these cells are others of larger calibre, but whose walls are thickened and likewise stained brown. The former is wood or libriform tissue, and the latter vasiform tissue, consisting of ducts or tracheids of various kinds. Both, like the bast-fibres, are mechanical tissues, their functions in the stem being chiefly those of strengthening and conveying nutriment.

(7) Interior to this zone of wood, as it is called, is a large-celled parenchyma substantially like that between the zone of cork and that of bast-fibres except that the cells are mostly larger: this is the pith-parenchyma. The outer layers of it consist of smaller cells more compactly arranged, while the inner part is composed of relatively large cells with rather conspicuous intercellular spaces. The pith-cells are rich in starchy contents, but often contain but little protoplasm, and in very old cells there is none at all. Usually from these the starch also has disappeared.

II. Longitudinal Section.—By making a thin section that runs lengthwise of the stem near its middle, and treating it as the last was treated, there will be discovered other important differences between the different tissues. But first the method of making good longitudinal sections with the razor should be learned. Let first a piece of the stem from three to five centimetres long be taken. By means of a sharp pocket-knife the stem is cut transversely about six millimetres back of one end to a trifle beyond its centre; then the knife-blade is withdrawn, and

by placing it at the end of the stem the latter is split down to the transverse cut, and a portion extending not quite to the centre is removed from the stem. The razor should not be used for this purpose, because of the danger of notching it. Now let the larger portion of the stem be taken, and, after having carefully smoothed off with the razor the split surface, let sections be made as follows: Using the unsplit portion of the stem for a handle, and extending the forefinger to guide and steady the razor-blade, it will now not be difficult to cut, with a steady, oblique, pushing motion, a few thin and even sections. These should immediately be transferred either to water or to alcohol. The blade should be kept wet with water or with alcohol while cutting, and care should be taken that the sections run directly lengthwise of the grain and not far from the centre of the stem. Now, by means of a brush, let one of the sections be transferred to a slide, and, after soaking up any adhering liquid with blotting paper, immediately cover it with the zinc-chloriodide iodine, and after a few minutes examine it. Another section should be treated with the phloroglucin reagent and be mounted similarly.

Studying the sections now, it will be found that the cork-tissue does not look very different in this view from that seen in the transverse section; the collenchyma-cells, however, are elongated in the direction of the length of the stem; but the greatest difference is in the prosenchymatous tissues, the bast-fibres, wood-cells, and ducts appearing very much elongated and either oblique-ended or taper-pointed. Most of the cells of the soft bast and cambium are also observed to be several times as long as broad.

The student should now study by similar methods some other of the kinds of stems mentioned at the opening of this exercise, and note, by means of drawings and otherwise, the result of his work.

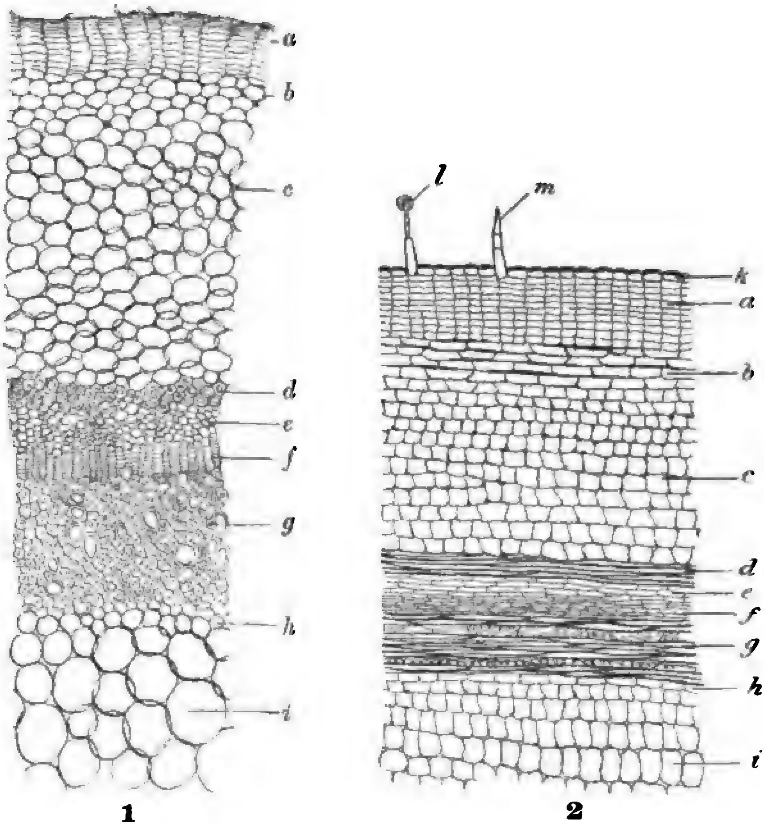


PLATE XXXIX., FIG. 1.—Portion of Cross-section of Stem of Pelargonium zonale, extending from the exterior to the pith, and showing all the different kinds of tissues : *a*, cork-tissue exfoliating at the surface ; *b*, collenchyma ; *c*, cortical parenchyma ; *d*, bast-fibres ; *e*, soft bast ; *f*, cambium zone ; *g*, zone of wood consisting of wood-cells and ducts of various kinds ; *h*, small parenchyma-cells at outer border of pith ; *i*, large parenchyma-cells forming main portion of pith.

FIG. 2.—Portion of Longitudinal Section of another and somewhat younger Stem of the same species : the letters *a* to *i*, inclusive, refer to the same parts as in the previous figure ; *k*, the epidermis, in this specimen not yet displaced by the cork-cells forming beneath ; *l*, a glandular hair ; *m*, an ordinary hair. (Both figures magnified about 50 diameters.)

EXERCISE III.

STUDY OF PARENCHYMA.

ORDINARY parenchyma is a very abundant tissue, and may be studied to advantage in the roots, stems, and leaves of almost any flowering plant or fern. In herbs and aquatics it constitutes by far the largest proportion of the plant; in woody plants, though much less abundant, it still exists in considerable quantity.

Besides the ordinary form there are several varieties or modifications, such as stellate parenchyma, where the cells are star-shaped; folded parenchyma, where the walls have internal folds; spongy parenchyma, where the cells are very loosely arranged; palisade parenchyma, where the cells are elongated and arranged somewhat like the posts of a palisade; and pitted parenchyma, where the walls are pitted or marked by thin places of various dimensions and shapes in different cells. Ordinary and pitted parenchyma will be studied in this exercise; the rest, farther along in the course.

I. ORDINARY PARENCHYMA OF PUMPKIN STEM.—Making a thin transverse section, mounting it in a few drops of potassium-iodide iodine, and examining it under a low power, it is observed—

(1) Parenchyma is the most abundant tissue of the stem; it consists of thin-walled, rounded or polygonal cells having small angular intercellular spaces, the cells being rich in protoplasm. These facts agree with what has already been observed in the parenchyma of the Geranium stem; they agree also with the structure of ordinary parenchyma-tissue in general. If a longitudinal section be made and the tissue be examined, it will be found that in this view it does not appear markedly different from that in the transverse section; the cells, that is, are not much longer than broad, and are blunt-ended, as is usually the case with par-

enchyma-cells. Ordinary parenchyma-cells may sometimes be found that are two, three, or in rare instances even several times as long as broad, but even then they are blunt or square-ended, not acute, oblique, or taper-pointed.

(2) As the walls have not been stained by the reagent used, it may be inferred that they are composed of cellulose, and therefore would probably stain blue with the chloriodide-of-zinc iodine. Since this reagent will aid to further knowledge of the structure of the tissue, a new section should be prepared and be treated with the chloriodide on another slide. After the blue color characteristic of cellulose has been developed in the walls, it will readily be seen, if the high power be turned on, that the walls are not uniformly colored, but appear punctate with nearly colorless dots. These dots are not apertures, as might at first be supposed, but are thin places in the wall, consisting really of little more than middle lamella. It is learned from the test that, thin as the walls of the cells are, they are not of even thickness. This is true of the walls of all cells which have reached maturity, but the inequality is usually greatest in the walls that have become considerably thickened, and it is by reason of this fact that some thickened cell-walls have very conspicuous markings, such as pits, bars, spirals, and so on.

(3) Returning now to the section that was treated with the potassium-iodide iodine, let the cell-contents be studied. It will be found, as was done in the cells of the Onion scale, that the cells contain protoplasm and a nucleus, and in these may be distinguished nearly the same structure. On the outside is the primordial utricle, which in places has been shrunken away from the cell-wall by osmosis; in the centre, or sometimes in contact with the wall of the cell, is the rounded, distinctly outlined nucleus, containing two or more nucleoli; there are the plates and bands of protoplasm connecting the nucleus with the primordial utricle; and between the plates and bands are sap-spaces or vacuoles. Here, as in all protoplasm, are found very minute granules, the *microsomes.*

Besides the microsomes there are other granules, rounded or oblong in form, of much larger size, and stained brown like the protoplasm and nucleus, only deeper, because they are denser. They are the *chloroplasts*, or chlorophyll-bodies; in the fresh stem

they are green in color by reason of the chlorophyll they contain. It is the coloring matter in these chloroplasts which gives the green color to the leaves and other green portions of the plant.

There are other granules, dense, rounded, and stained so deeply as to appear black with the strong iodine solution used: these are of an entirely different nature, not proteid at all, but starch-grains, as may readily be proved by using on a fresh section a little of the iodine solution much diluted with water, when they will show their proper blue color. Or the same object may be compassed even better by the use of a few drops of the chloral-hydrate iodine, which dissolves the proteids and causes the starch-grains to swell slowly, at the same time staining them the characteristic blue color.

If the parenchyma examined is from near the outside of the section, it will be found that the chlorophyll bodies are numerous; if from farther interior, few or none will be seen, while here the starch-grains are usually more abundant.

II. PITTED PARENCHYMA FROM THE STEM OF THE SAGO PALM (*Cycas revoluta*).—This modification of parenchyma, though much less common than that just described, is still easy to observe, being found in the pith of many woody plants, as in that of Pilocarpus selloanus, *Engler*, P. Jaborandi, *Holmes*, Asimina triloba, *Dunal*, Magnolia grandiflora, *L.*, and Magnolia glauca, *L.*, in the parenchyma between the bundles in the stems of most woody monocotyls, and in the medullary rays of a large proportion of the woody dicotyls.

(1) If a transverse section of the petiole of the Sago Palm be made, and merely mounted in water without staining, it will be seen that the rather thick-walled parenchyma shows many transparent, rounded or oblong areas, that, being colorless, look like perforations. They are not perforations, however, but are merely thin places perfectly analogous to those already observed in the thin-walled parenchyma of the pumpkin stem; only here, owing to the much greater thickening of the rest of the wall, they are more conspicuous. They even give to the edges of the cell a distinctly beaded appearance.

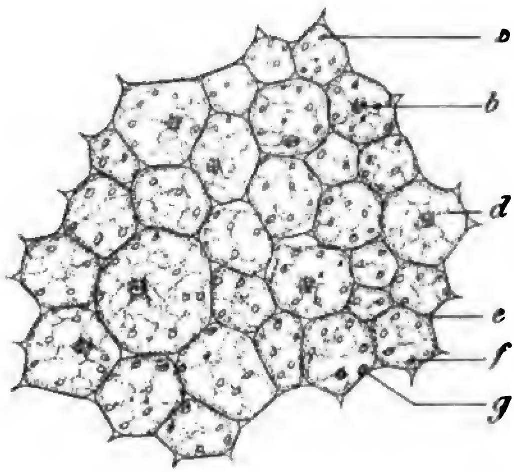
(2) If the cover-glass be taken off and the phloroglucin or aniline-chloride test be applied, it will probably be found that the thickened walls of the parenchyma-cells are also somewhat ligni-

fied, though not nearly so strongly as the wood-cells and ducts which may be seen in the same section.

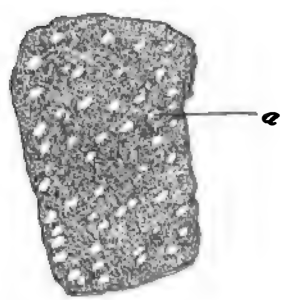
(3) A still better idea of the structure of these cells will be obtained, however, if some new sections, both longitudinal and transverse, are made and are treated as follows: If the sections are cut from fresh tissues, they should be plunged into alcohol or acetic alcohol for a few moments to fix the protoplasm and to facilitate staining; they are then washed in water and placed for about fifteen minutes in a dish containing a little of the gentian-violet solution; they are again washed, this time in alcohol, to remove the excess of stain, in the last washing causing them to pass through absolute alcohol so that they become anhydrated, and are then laid for fifteen or twenty minutes in eosin oil of cloves, which both clears the section and removes most of the gentian-violet that is left in the cellulose tissues, while at the same time it communicates its own color to them. The thicker portions of the wall are now found to have retained the violet color, while the thin portions are unstained by it, but are distinctly colored by the eosin, thus proving that they are not perforations.

The staining also reveals the fact that the cells contain protoplasm and a nucleus.

Between this rather thick-walled and distinctly pitted parenchyma and the ordinary kind there are found in different plants, or often even in the same plant, every gradation; and, on the other hand, there may also occur every gradation between it and sclerotic tissue, soon to be studied.



1



2

PLATE XL., FIG. 1.—A small portion of the Parenchyma as seen in a transverse section of the stem of the Pumpkin (magnification about 60 diameters): *a* and *f*, chloroplasts; *b*, the nucleus; *d*, ordinary protoplasm; *e*, small, angular intercellular space; *g*, a starch-grain.

FIG. 2.—A small portion of the Cell-membrane of one of the Parenchyma-cells (magnified 500 diameters), showing the small pits. The drawing was made from a section which had been stained by means of zinc-chloriodide iodine. *a*, one of the pits.

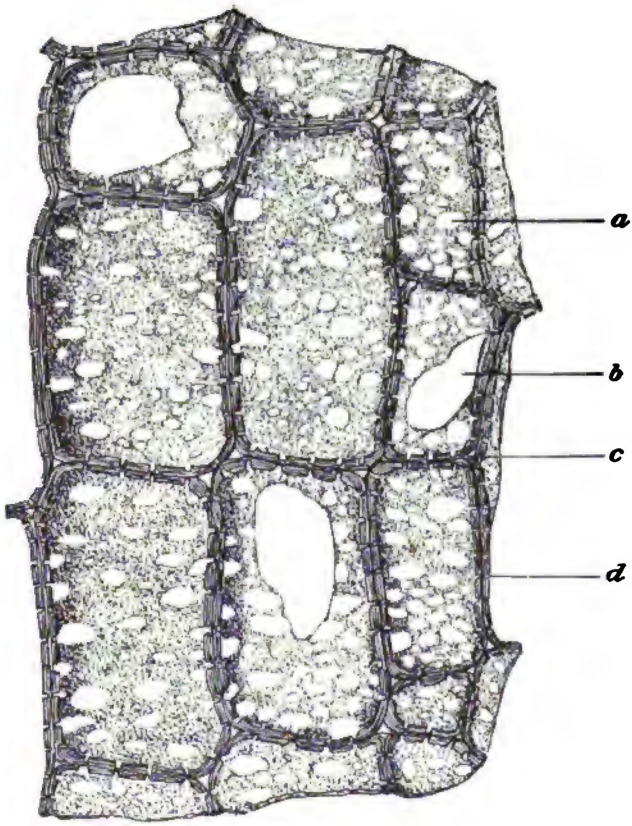


PLATE XLI.—A few Cells of Pitted Parenchyma, drawn from a longitudinal section of the petiole of Cycas revoluta (magnification about 210 diameters): *a*, one of the thin places or pits; *b*, space where a portion of the wall has been cut away by the section-knife; *c*, intercellular space; *d*, one of the pits seen edgewise in the cell-wall.

EXERCISE IV.

STUDY OF COLLENCHYMA.

THE following objects are easily obtainable, and afford convenient examples for study: the petioles of almost any species of the cultivated Begonias; those of almost any species of Grape, of the Sumach, of Burdock, of Pie-plant, and of Plantain; the stems of the Yellow Dock, the Pumpkin, the Ohio Buckeye, of Joe-Pye Weed (Eupatorium purpureum, *L.*); and the stems and petioles of Spikenard (Aralia racemosa, *L.*).

I. THE PETIOLE OF BEGONIA DISCOLOR (*H. K.*), a common greenhouse plant, will be the subject of the present study. Let a transverse section first be made, as thin a one as possible, and mounted, without exerting pressure on the cover-glass, in a few drops of the strong potassium-iodide iodine solution. Care should always be taken, especially in the study of fresh or unhardened sections of delicate tissues, not to put on the cover-glass in such a way as to exert more than the minimum of pressure on the section, otherwise the cells will be crushed or inclined to one side, making it difficult to understand the structure. Having obtained a successful mount, let it be examined first with the low power and afterward with the high one.

(1) At the very periphery of the section is seen the epidermis, consisting of a single tier of cells, and immediately beneath or interior to this is the tissue to be studied—the thick-angled tissue, or collenchyma. It consists usually in this species of about five or six layers of cells of varying sizes, but averaging considerably larger than those of the epidermis exterior to them, and smaller than those of the parenchyma interior to them.

It is in this position—namely, just interior to the epidermis or to the cork that may be formed from it—that collenchyma, when present at all, is usually found. It very rarely occurs elsewhere in the plant. It is pre-eminently a strengthening tissue to the epidermis, and sometimes, as in the present instance, forms a continuous band or zone about the sublying tissues; at others

it is interrupted at intervals, and forms long bands or strings running lengthwise of the organ, as in the stem of Yellow Dock and in the stems and petioles of many Umbelliferæ.

(2) The most distinguishing characteristic of collenchyma is readily seen—namely, the thickened angles of the cells. These thickenings in most cases are great enough to obliterate completely the intercellular space, though sometimes a portion of this still remains, as may often be seen in the petioles of Pie-plant. In some plants these thickenings are excessive, so as strongly to encroach upon the lumen of the cell; in other instances they are but slight. In some species the thickening is confined to the angles, while in others it may extend, to a less degree, to the entire wall.

It is easily determined, by aid of the sulphuric-acid-and-iodine or by the chloriodide-of-zinc iodine test, that the thickenings in the present instance are of cellulose, and not of lignin; and this is usually the case with this tissue, though in a few instances, where the thickenings are excessive, there is more or less of lignification.

Under a high power delicate stratification-lines may be observed in the more prominent thickenings. These are common in thickened walls generally, and are due to differences in the amount of water contained in different layers, making some more transparent than others. That this is the case may be demonstrated by removing the water completely by treatment with a considerable quantity of absolute alcohol, when the lines disappear. There are also other ways of proving the same thing, as will be demonstrated in a future exercise.

(3) The iodine test shows that these cells, like the parenchyma-cells farther interior, contain protoplasm, a nucleus, and chlorophyll-bodies. They are therefore not merely mechanical tissues, but take an active part in the vital processes of the plant.

Occasional cells, usually larger than the rest, are seen to contain stellate masses of crystals. If to a fresh section there be applied two or three drops of strong acetic acid, it will be found that even after some time the crystals remain unaffected; but if to a similar section a few drops of strong hydrochloric acid be applied, the crystals slowly dissolve without effervescence. Had they been composed of calcium carbonate, they would have effervesced and passed into solution in both acids; had they been

composed of silica, they would not have been affected by either. Since, therefore, it is known that calcium oxalate is soluble without effervescence in hydrochloric acid, but not in acetic acid, the conclusion is that the crystals are of this substance—the commonest by far of all the crystalline substances in plant-cells.

II. LONGITUDINAL VIEW OF COLLENCHYMA.—Let there now be made a longitudinal section of the petiole nearly through its centre, in the same manner as directed in Exercise II. Care must be observed to cut the sections very thin, otherwise the structure cannot well be seen, owing to the overlapping of the cells. The sections should now be treated with chloriodide-of-zinc iodine, so that the cell-walls may easily be traced. The longitudinal view of the tissue appears quite different from the transverse view, partly because of the thickenings—which are now seen lengthwise, appearing as long, narrow bands—and partly because the cells themselves are considerably elongated in the direction of the section. As to their length, however, they differ much among themselves. Some are no more than twice as long as broad, while others may have a length five or six times the thickness. It will be observed that the narrower cells are usually the longer, as though what had been gained in length had been sacrificed in thickness. The cells containing crystals, being of great transverse diameter, are also short. It will be observed, furthermore, that the cells are blunt-ended, never taper-pointed, agreeing in this respect with parenchyma-cells. In fact, the tissue as it occurs in this plant is not very greatly modified from ordinary parenchyma. In some other plants, however, it is found tending strongly toward fibrous tissue. Its cells are greatly elongated, the walls much thicker, the ends more inclined to oblique or tapering forms, and in some instances the walls even somewhat lignified, forming a tough and strong tissue more exclusively devoted to mechanical functions.

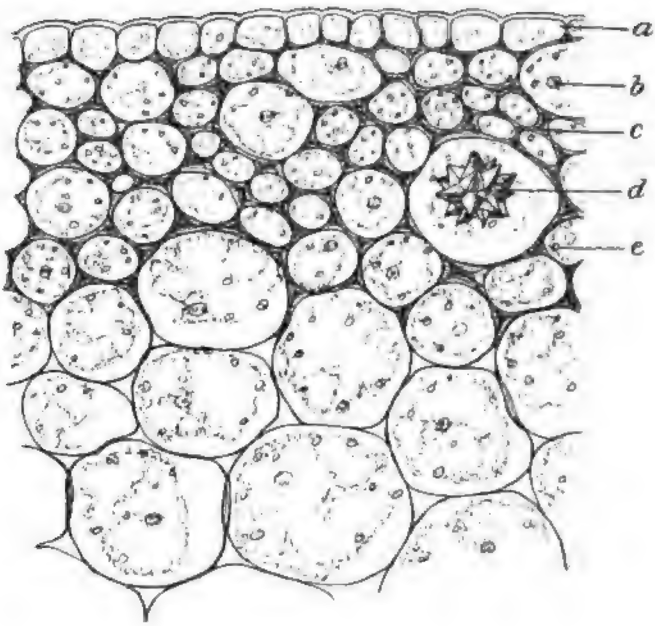


PLATE XLII.—Small portion of Petiole of Begonia discolor (transverse section, magnified about 210 diameters): *a*, epidermal cell; *b*, nucleus of a collenchyma-cell; *c*, thickened angle of the collenchyma-tissue; *d*, mass of crystals of calcium oxalate in a large collenchyma-cell; *e*, a chloroplast.

EXERCISE V.

STUDY OF SCLEROTIC PARENCHYMA.

GOOD examples for study occur in most of the nuts, particularly the Hickory-nut, Pecan, Hazel-nut, English Walnut, and Cocoanut; in the flesh of the Pear, the gritty particles in which consist of this tissue; in the pith of the stem of Menispermum canadense, *L.*, and in that of the Apple twig; in the leaves of Tea and Camellia; in the stem-barks of Ceylon cinnamon (Cinnamomum Zeylanicum, *Breyne*), the Sweet Bay (Magnolia glauca, *L.*), the Umbrella Tree (Magnolia Umbrella, *Lam.*), the Flowering Dogwood (Cornus florida, *L.*), and the Custard Apple (Asimina triloba, *Dunal*); and in the root-barks of the Dogbane (Apocynum androsæmifolium, *L.*), the Butterfly Weed (Asclepias tuberosa, *L.*), the Yellow Dock (Rumex crispus, *L.*), and the Hop tree (Ptelea trifoliata, *L.*).

Sclerotic tissue, often from its hardness called "stony tissue," is, as found in the shells of nuts, for example, very difficult to cut without resorting to some softening process. Softening may be accomplished by soaking the tissues for a week or more in a 5 or 10 per cent. aqueous solution of potassium hydrate, and then washing out the alkali by means of clean water or water which has been slightly acidulated with acetic acid. Good sections may now be cut with a razor, even of such hard structures as the shells of the Hickory-nut or Cocoanut, without much danger of notching the blade, providing it be not allowed to run too deep. The darkening of the tissue, which is often one of the results of the process, may be corrected either by treating the sections with the sulphurous-acid alcohol described in the Introduction, or by bleaching them with Labarraque's solution, taking care to carry the bleaching process only so far as to get rid of the coloring matters. The sections may then be washed thoroughly, stained with safranin solution or with a solution of iodine-green, anhy-

drated by means of absolute alcohol, and permanently mounted in balsam.

But for the laboratory a method which is less time-consuming is more desirable, hence the following may be adopted: With a thoroughly sharpened pocket-knife cut a number of thin sections parallel to the surface of the shell, and place these sections by themselves in a dish of water. It does not matter that they are of small size or fragmentary if they are cut thin. After soaking for a few minutes in the water, particularly if it be heated to near the boiling-point, the sections, which usually roll up in cutting, may be flattened out by means of dissecting-needles or by means of a needle and a brush, and then be mounted in a drop of water or glycerin, and examined. The edges at least will be transparent enough to permit of the cells being seen distinctly.

(1) For this study the shell of the Cocoanut is selected, and by means of the process last described a dozen or more sections are cut parallel to the surface of the nut, and as many from the edge of a broken piece, or perpendicular to the surface. One or two sections of each kind are now mounted on different slides.

The section made parallel to the surface is first examined. Focusing with the low power upon the thinnest part, there is seen a mass of cells which are rounded, somewhat polyhedral, or slightly elongated in form, pressed so close together that no intercellular spaces are visible, and having excessively thick walls. On or in the walls are seen minute dots or punctulations, as well as radial lines connecting the very small cavity or lumen of the cell with the middle lamella. Many of the lines are simple, while others branch before reaching the exterior. With the high power and under favorable illumination one may readily convince one's self that the lines are really minute tubes beginning at the lumen and terminating at the middle lamella. The dots, too, are of the same nature, as may be learned by focusing up and down; they are small tubes looked at endwise, and therefore appearing round or dot-like. The tubes may be rendered more distinct by flattening out one of the sections on a slide, drying it over an alcohol lamp so as to expel the water from the tubes and lumen, putting on a drop of balsam, and covering with a cover-glass. The tubes are now easily traceable because

filled with air. They are called *pore-canals*, and, strange as it may seem, they are perfectly analogous to the pits observed on ordinary parenchyma-cells. They are, like the latter, thin places in the wall, but by reason of the excessive thickening of the rest of the wall they have become lengthened into tubes. They probably serve the purpose of facilitating the circulation of nutritive fluids from cell to cell. A further evidence that this is the case is the fact that the termination of the tube in the middle lamella is nearly always opposite one in an adjacent cell; that is, the ends are separated from each other only by the middle lamella.

Employing good illumination and the high power, it will be found also that the thickened walls show delicate stratification-lines forming a series of concentric curves about the lumen. If a section be mounted in water, and then, after focusing upon a part of it that shows the cells sharply defined, a drop of chloral-hydrate solution be allowed to run under the cover-glass, and in the mean time the result be closely watched as the swelling reagent comes into contact with the walls, it will be seen that the lines come out more distinctly, but after a time, owing to continued swelling, they become less distinct. Cuprammonia may be employed in the same way, but it works more rapidly, and its effects are therefore more difficult to observe.

Comparing now the sections made perpendicular to the surface with those already studied, it will be found that there is but little difference except that the cells are on the average longer in the section made perpendicular to the surface than in the other, though rounded and elongated forms are found in both sections. In form, therefore, the cells are essentially like ordinary parenchyma-cells: they are, in fact, parenchyma-cells in which the thickening process has been carried much farther than in the pitted parenchyma just studied—so far, indeed, that the lumen has been nearly obliterated, and the cell has ceased to take part in the vital processes of the plant.

Between ordinary parenchyma-cells and these sclerotic ones every possible gradation is found.

(2) Let now an effort be made to ascertain whether the thickening deposits in the wall are of cellulose, like those of collenchyma, or of lignin. The application of the phloroglucin test to

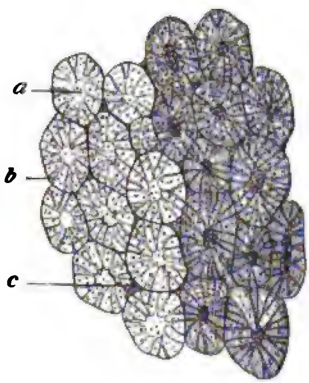
a fresh section speedily dispels any doubts that may have arisen on the subject, for the walls are stained a deep-red, the characteristic reaction for lignin.

This tissue therefore grades toward the mechanical tissues of the prosenchymatous series, and in some instances, where the cells are elongated and even fusiform in shape, it becomes difficult, if not impossible, to tell them from sclerenchyma-fibres.

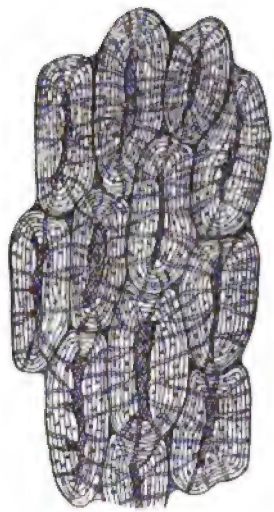
(3) There may be learned, in connection with this tissue, the method of isolating cells by means of Schulze's process. Also in the isolated cells the variety in their shapes may be seen more readily than when studied in mass.

A few of the sections are placed in a small porcelain evaporating-dish, and a small quantity of strong nitric acid in which a few crystals of potassium chlorate have been dissolved is poured upon them. Better results are obtained if the sections be allowed to stand in the cold solution for fifteen minutes or more, to give the liquid time to penetrate to all parts of the structure. Heat is then applied very gently, and meantime the process is watched carefully. The sections soon turn a deep-brown color, and presently effervescence begins. Heat should thereafter be only very cautiously applied, if at all, and when the brown color has disappeared from the sections the contents of the dish should immediately be poured into a large quantity of cold water to stop further action. After the acid has been mostly removed from the sections by soaking them for a few minutes in clean water, they may be stained with methyl-green or with iodine-green and be mounted in clean water, when, by gently tapping the cover-glass with a needle-point, the cells will separate readily from each other. This is by reason of the fact that the middle lamella is more readily soluble in this reagent than is the rest of the cell-wall.

The cells may easily be mounted in permanent form by removing the cover-glass, soaking up the superfluous water with blotting paper, putting on a drop of liquefied glycerin gelatin, and again covering.



1



2

PLATE XLIII., FIG. 1.—A group of Sclerotic Parenchyma-cells from a section of the Cocoanut shell (magnification about 330 diameters). The section was tangential, or made parallel to the surface of the nut. The cells to the right show both the pore-canals and the stratification-lines, while from those to the left the latter have been omitted to show the former more distinctly. *a*, lumen of a cell; *b*, a branching pore-canal; *c*, middle-lamella.

FIG. 2.—A portion of the same kind of Tissue from a Radial Section (magnified about 400 diameters).

EXERCISE VI.

STUDY OF EPIDERMAL TISSUE.

THE epidermis may readily be stripped off from the leaves of any of the following plants, which therefore afford convenient objects for study: most of the Cultivated Lilies; the Garden Hyacinth; the Tulip; most of the cultivated species of Amaryllis, Agapanthus, and Narcissus; Tradescantia Virginica, *L.*; some species of Sedum, as, for example, the Common Live-for-ever (Sedum Telephium, *L.*); the Gentians, as Gentiana alba, *Muhl.*; and some of the cultivated species of Begonia, as Begonia discolor, *H. K.*

In other instances, where the epidermis is too fragile or too closely adherent to sublying tissues to separate readily, good preparations of it in the fresh condition may still be made by carefully scraping away with a knife-blade the tissues next to the epidermis until the chlorophyll-bearing cells are removed.

For the present exercise is selected the epidermis from the leaf of the Tulip. This may be obtained, in pieces of sufficient size, in the manner described in the case of the Onion scale. Let the epidermis from the under or dorsal surface of the leaf first be studied.

(1) After transferring a piece of the epidermis to the centre of a slide and treating it for a few minutes with the strong solution of potassium-iodide iodine, it is covered, and examined first with the low and then with the high power.

It will be seen that the ordinary epidermal cells are arranged very much as in the Onion. They are considerably elongated in the direction of the length of the leaf, the ends are blunt, and the cells are so arranged as to leave no intercellular spaces. This is true of ordinary epidermal cells generally, and in this respect they differ markedly from those of parenchyma-tissue.

The cells are rich in protoplasm. The primordial utricle, the nucleus, the nucleoli, and the threads and bands of protoplasm are all as distinctly recognizable as in the cells of the Onion

epidermis already studied, and are very similar in appearance to the cells of the latter. The vacuoles are also abundant, and many of them form transparent globules of various sizes.

But a conspicuous difference is the presence of *stomata*, or so-called breathing-pores—small apertures between a pair of crescent-shaped cells called *guard-cells*. These pores were not found in the epidermis of the Onion scale, because this was not exposed to the light. The epidermis of the colorless scales of parasites, of the scales of ordinary plants where not exposed to light, and of roots and subterranean stems, ordinarily does not possess stomata, but that of all green parts of plants above the mosses in the scale of life usually possesses them in abundance, except that they are often absent from the epidermis of the upper surface of leaves. The stomata are the openings through which the plant gets rid of the superfluous water it takes up chiefly through its roots, through which it exhales that portion of the disengaged oxygen which it does not require, and through which it takes in the carbon dioxide which it needs for food. They are apertures which also automatically dilate or contract, or even completely close, according to the condition of the atmosphere and the necessities of the plant. If the air is dry and there is need for the plant to conserve its moisture, the stomata contract; if the air is moist and the plant has more water in its tissues than is needed, they expand. The mechanism by which these movements are accomplished will presently be discussed.

The guard-cells are much smaller than the ordinary epidermal cells and are much richer in proteid matters, containing, besides a crescent-shaped nucleus and ordinary protoplasm, numerous chloroplasts and occasional oil-globules. The chloroplasts, it will be observed, are not present in the ordinary epidermal cells. This is true of the epidermis in most plants—a fact which accounts for its transparency.

(2) Let now a transverse section of the epidermis be made—that is, a section through it which is perpendicular to the longest diameter of the leaf; for in order to understand the structure of a stem it is necessary to have a section which crosses the two guard-cells near their middle, and, since the stomata all point in the same direction—namely, lengthwise of the leaf—this is the only section which will serve the purpose. It is necessary, more-

over, to have the section quite thin. It is readily made as follows: Cut out of the leaf a piece about half an inch square, and orient it properly between the flat surfaces of two pieces of elder pith. Holding the combination rather firmly between the thumb and the fingers, very thin sections may be cut through pith and all, and those of the leaf may be picked out by means of the pincettes.

The pith for this purpose is best prepared as follows: Take a piece about four centimetres long and halve it lengthwise, not by placing the edge of the razor across one end and forcing it through toward the other, but by placing it parallel to the length of the cylinder and cutting it as nearly as possible through the middle. The danger of breaking it into small fragments is thus avoided. Between the flat surfaces of the two semi-cylinders thus produced is placed the leaf to be sectioned.

The sections, as soon as cut, should be transferred to water to prevent the entrance of air; but care must be taken to keep the pith dry during the process of sectioning, for if moistened it does not cut well.

Having prepared thus several good sections, one is selected, and by means of a camel's-hair brush is transferred to a slide and mounted in a drop of water. Since the weight of the cover-glass is sufficient to crush and spoil a section so delicate, it is best that the slide used should have a ring of cement or of sheet wax in its centre, a little smaller in diameter than the cover, and of sufficient thickness to relieve the section of the pressure.

On placing the preparation under the microscope now, it will be found that the epidermis consists of a single layer of cells, which in this view are squarish in outline, quite thick-walled exteriorly and only a little less so interiorly, but with the radial walls rather thin. At intervals occur cells in pairs, smaller, of different shape, and with more granular contents. These are the guard-cells. If the section happen to run squarely through their middle, it will be possible to see the stoma or opening itself.

Underneath the epidermis are found relatively large, rounded, thin-walled parenchyma-cells having between them conspicuous intercellular spaces and containing numerous chloroplasts. The stomata, it will be observed, always open into a large intercellular space. Owing to this arrangement the outside air, when the stomata are open, is in free communication with the whole inte-

rior of the leaf, since air can circulate freely through the intercellular spaces. The importance of this fact to the functions already mentioned will readily be understood.

But while there is this free communication between the interior and the exterior through the stomata, the walls of the epidermal cells are all highly impermeable to water, for the epidermis, as would be found by testing it, is strongly cutinized, and cutin is of all vegetable substances one of the least permeable to water. The function of cutinized epidermis in preventing excessive evaporation is strikingly shown in the case of the leaf of the common Live-for-ever and in that of Bryophyllum. If a leaf of either be plucked and exposed to the sun and dry air even for a considerable time, it scarcely shows signs of withering; but if the epidermis first be stripped off, the leaf will shrivel and dry in the course of a few minutes.

(3) *Mechanism of the Opening and Closing of the Stomata.*— The movements of the guard-cells by means of which the aperture between them is enlarged or contracted are effected by means of their hygroscopism—that is, by their power to take up moisture from the air about them and to part with it. When the air is moist the guard-cells imbibe moisture and swell, but they are so placed as respects the other epidermal cells, and the thickenings of their walls are so adjusted, that in swelling the cells must bow out in the middle, thus increasing the size of the aperture; and when, on the other hand, the air is dry and they part with moisture, the cells become flatter, less convex on the outer or more remote surfaces, and less concave on the inner ones, or those next the aperture, thus either diminishing the latter or closing it completely. The cross-section shows that the more remote walls remain quite thin, thus permitting a movement in a direction parallel to the surface of the epidermis and perpendicular to the length of the guard-cells, while movements in other directions are not possible. Careful tests, moreover, show that while the outer part of the cell-walls, and even the inner part, is cutinized, the radial walls are not only not cutinized, but are quite thin throughout a considerable portion of their extent, so that they can readily take up moisture and as readily part with it. When the stoma is closed, however, only cutinized surfaces are presented to the outer air, and evaporation is thus shut off.

(4) *How does the Epidermis of this Plant differ from that of Others?*—It would take too long to answer the question fully, but some of the most important differences may be pointed out:

(*a*) In the majority of cases, as in this, the epidermis consists of a single layer of cells, but in some it consists of two or more.

(*b*) In many cases the epidermis is smooth, as in this, but in the majority it is hairy or glandular.

(*c*) In most of the higher plants the ordinary epidermal cells are free from chloroplasts, as in this, but in ferns they are present.

(*d*) In many other plants besides this, particularly of the monocotyls, the epidermal cells are quadrilateral, or at least but slightly wavy in outline, but in the majority of plants they are strongly wavy or sinuous in outline.

(*e*) In some cases, as in this, the inner wall is nearly as strongly thickened as the outer, but in the majority the outer is much the more strongly thickened and cutinized.

(*f*) Great differences exist in the number of stomata. While the variation is not usually very wide within the limits of the species, different species often differ greatly from each other in this respect. For example, there are, according to Weiss, in the epidermis of the under side of the Oat leaf 2700 to the square centimetre, while in the under side of the leaf of the Olive there are 63,500 to the square centimetre.

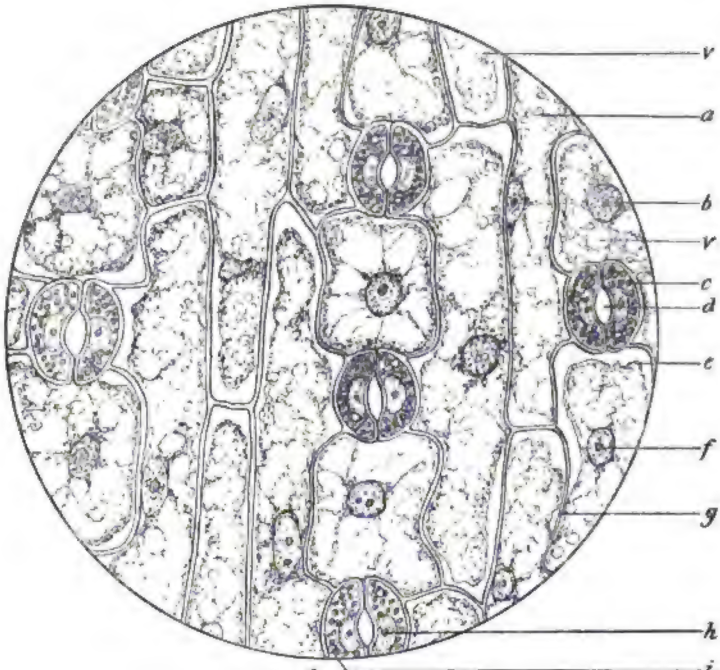
(*g*) There are differences in the arrangement of the stomata. In some plants they are distributed in rows running lengthwise of the organ; in others they are scattered without apparent order. In some cases they point invariably in one direction; in others they may point in any and every direction. In rare instances, as in the Oleander leaf, they are bunched together in hollows or depressions in the under surface of the leaf, and do not occur elsewhere upon it.

(*h*) The epidermis of different species differs too in the structure of the stomata. In the majority of cases the stomata consist, as in this instance, of two crescentic guard-cells with the opening between them, but sometimes there are two or more superposed pairs of cells; rarely they form canals or channels whose walls are composed of several superposed circlets of cells with several cells in each circlet.

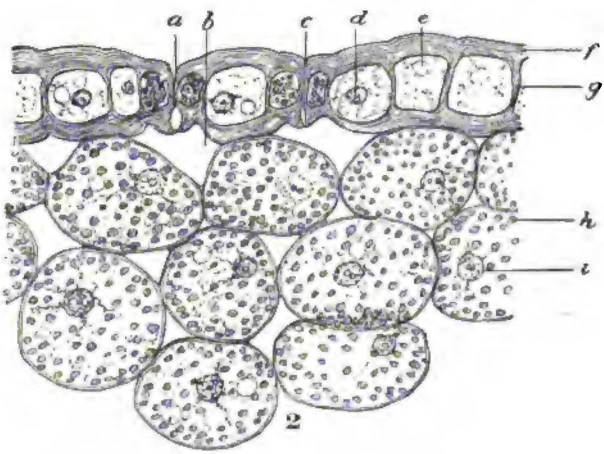
(*i*) Differences occur also in the level of the insertion of the

stomata. Very commonly the guard-cells are on the same level as that of the other epidermal cells; in some species they rise above that level, and in some other species they are depressed more or less below it.

(*k*) The stomata differ also in different species as respects their relation to adjacent cells. Sometimes they are scattered among ordinary epidermal cells, but not infrequently the cells immediately surrounding them are more or less modified in form and structure, so as evidently to be subsidiary to them. Such cells are called "accessory cells." In one instance—that of Aneimia fraxinifolia—according to Strasburger, the guard-cells are placed within an ordinary epidermal cell very much as a picture within its frame.



1



2

PLATE XLIV., FIG. 1.—Lower Epidermis of the Tulip, view of the exterior surface. The drawing was made from a portion of the tissue which had been treated with potassium-iodide iodine (magnification, 285 diameters): *v*, *v*, vacuoles; *a*, protoplasm; *b*, nucleus; *c*, chloroplast in one of the guard-cells; *e*, primordial utricle shrunken away from the cell-wall by the action of the iodine solution; *f*, nucleolus; *g*, cell-wall; *h*, nucleus and nucleolus of guard-cell; *i*, oil-globule in guard-cell.

FIG. 2.—Small part of Transverse Section of the Leaf, showing a portion of the lower epidermis and a few of the adjacent parenchyma-cells: stomata are indicated at *a* and *c*; *b*, the air-chamber adjacent to a stoma; *d*, nucleus of an ordinary epidermal cell; *e*, a vacuole; *f*, cutinized exterior wall; *g*, thin radial wall; *h*, a chloroplast in one of the parenchyma-cells; *i*, nucleus of one of the parenchyma-cells. (Magnification the same as in Figure 1.)

EXERCISE VII.

STUDY OF EPIDERMAL APPENDAGES.

THE following will afford interesting studies: young stems and leaves of the Sycamore (Platanus occidentalis, *L.*); those of the Hickory (Carya alba, *Nutt.*); those of the Nettle (Urtica dioica, *L.*); those of Shepherdia (Shepherdia Canadensis, *Nutt.*); those of tobacco (Nicotiana Tabacum, *L.*); those of the Mullein (Verbascum Thapsus, *L.*); those of Mentzelia (Mentzelia oligosperma, *Nutt.*, or M. ornata, *Torr.* and *Gray*); those of the Horseshoe Geranium (Pelargonium zonale, *Willd.*); and the hairs on the filaments of the Spiderwort (Tradescantia Virginica, *L.*).

(1) For the first study is selected a stem of the Horseshoe Geranium which is not yet old enough for cork to have begun to form. Of this a half dozen or more thin transverse sections are made. Let one of these sections be placed on a slide, covered with several drops of the alcannin solution, and set aside under a bell-glass for half an hour or more to permit of satisfactory staining. Another of the sections may be treated with the chloriodide-of-zinc iodine and be put away in the same manner. A third is mounted in a drop of water and focused upon with the low power.

On exploring the margin of the section there will be found attached to the epidermis numerous hairs. These hairs are not all of the same kind, for some have a large rounded cell at the apex, while others are without such a cell. The former are the glandular hairs, the latter are ordinary simple ones.

Let first one of the simple hairs be examined. It will be observed to be long-conical in shape, and to be composed of a varying number of cells, usually three or four, placed end to end. The basal cell, more rounded and thicker than the rest, fits in among the other epidermal cells, and the apical cell is longer than the rest and terminates usually in a sharp point. The contents are transparent, though with care there may be discerned,

even without staining, a nucleus and a small amount of granular protoplasm.

The glandular hairs are of three different varieties. One variety is much longer than the rest, and consists usually of from five to seven cells arranged in a single series, the apical cell constituting the gland, the rest the stalk. The latter has its basal cell set in the epidermis the same as the simple hair just described. The cells above it taper gradually in size until the fourth or fifth cell is reached, when there is an abrupt contraction, the succeeding one or two cells being considerably narrower and thinner-walled.

The gland-cell is nearly globular, and is so densely granular that its structure can only with difficulty be made out without the employment of clearing solutions. On the upper surface, however, there is usually a transparent, highly refractive portion, the nature of which will presently be investigated more closely.

Another kind of hair is much shorter, the stalk consisting of only two or three rather short cells, and the gland consisting of a very granular cell which is usually oblong or ovate instead of spherical, and which is often unsymmetrically inserted on the stalk. The third kind of hair, the most abundant of all, is also short, but with its stalk composed of four or five very short cells. The gland is spherical like the one first described.

It is these glandular hairs which cause the clamminess of the leaves and branches, and it is they also which emit the volatile essence that communicates to the plant its peculiar odor.

Treating a fresh section with potassium-iodide iodine, it is found that the cells of both the simple and the glandular hairs contain abundant protoplasm in which may be recognized the usual structure belonging to living cells—the nucleus and nucleolus, the primordial utricle, and the threads and bands of protoplasm. Even in the densely granular gland-cells there may in some instances be recognized the nucleus, showing that they also, in this stage of growth at least, are living cells.

Besides the protoplasm proper there will also be found a few rounded or oval granules colored brown like the protoplasm. These are leucoplasts, like chlorophyll bodies except that they contain no chlorophyll.

To another section are applied a few drops of the chloral-hydrate solution for the purpose of clearing the gland-cells, that

their structure may the better be examined. The section should be examined immediately, before the liquid has had time completely to disorganize the protoplasm. In a few moments the gland-cell will be sufficiently clear to permit of the nucleus being recognized easily. Afterward the nucleus swells, and finally, like all the other proteids, is rendered nearly invisible. This clearing makes the cell-walls stand out with beautiful distinctness, and one becomes satisfied for the first time that the gland consists of a single cell.

Let now examination be made of the section which was treated with the chloriodide-of-zinc iodine, for the purpose of finding out whether or not the walls of the hair-cells are cutinized. It will be found that they are stained the same color as the rest of the epidermis. The interior of the walls may show a bluish tinge, indicating that cutinization is not complete, but the exterior is strongly cutinized.

Careful comparison of this with the previous section will render it evident that in those gland-cells which show at the top a transparent area the epidermal wall is divided into two parts, the exterior cutinized, the interior not cutinized or but slightly so, and that the refractive liquid lies between these two portions.

Sometimes it will be found, especially in older glands, that the cutinized portion is ruptured, the wall therefore more or less collapsed, and the refractive liquid accumulated in droplets on the outside. Some of the liquid seems, in fact, to be forced out by internal pressure before the wall becomes ruptured, as shown in Figure 2 (Pl. XLIV.). The conclusion naturally is reached that the refractive liquid, whatever it may be, is secreted by the granular protoplasm in the gland, and is forced out and accumulates between the non-cuticularized and the cuticularized portion of the wall, where, by reason of the impermeability of the latter, it accumulates until the pressure becomes so great as to force it through or finally to rupture the wall.

Let now an effort be made to ascertain the nature of the refractive liquid secreted by the glands. On soaking one of the sections for twenty minutes in absolute alcohol, evidence will be found that the secretion has passed into solution. The same result will also be reached if another section be treated for a few minutes with sulphuric ether. The secretion is, then, probably resinous or

oleo-resinous in its nature, for fixed oils are with few exceptions insoluble in alcohol. But resins and fixed and volatile oils are strongly colored by the alcannin solution. If, therefore, either of these bodies is present, the section that was treated with this solution should by this time show a deep-red color in the glands. An examination will show that this is a fact. The cutinized walls of the hairs and epidermis will also be found to be stained, though less intensely than the glands, while the rest of the section is scarcely stained at all. The conclusion therefore is reached that the contents of the glands are oleo-resinous.

Oleo-resins are quite abundant in plants, occurring often in glandular hairs, as in this instance, but frequently also in internal reservoirs. Some of these will be studied in a future exercise.

The hairs, especially the glandular ones, are probably chiefly protective, defending the younger and more vulnerable portions of the plant against insect enemies, and sometimes, by the irritant character of the secretions, even against the mammalia.

(2) For the second part of this study are selected the hairs on the filaments of Tradescantia Virginica.

In the fully-expanded flower the hairs are deep-blue in color, and look, under a low power, much like a minute string of blue beads. But, beautiful as they are, they are not sufficiently transparent, owing to the highly-colored sap, to permit the cell-contents to be seen distinctly, so, instead, the less highly-colored hairs from an unopened flower-bud are selected.

By means of delicate forceps a few of the hairs are carefully removed and mounted in a drop of water, precaution being taken, in putting on the cover-glass, not to crush or distort the cells.

On examining the cells with the high power a most striking phenomenon, a restless activity in the contents of the cell, will be seen. The nucleus, the nucleolus, the primordial utricle, and the bands of protoplasm are visible as in ordinary cells. The bands of protoplasm, however, are not constant in position, careful observation showing that they slowly shift their places in the cell; but the most striking thing is the rather rapid currents which are seen in the bands of protoplasm and in the primordial utricle, traceable by means of the numerous fine granules (microsomes) suspended in the transparent protoplasm. The currents may be seen running in the endoplasm up one side of the cell and

down the other, or passing off into the threads and bands that connect the primordial utricle with the nucleus. In some of the threads is observed a single current moving steadily in one direction, while in others may be seen two currents, side by side, running in opposite directions. The currents, however, are more or less shifting, as are the bands themselves.

This phenomenon is not exceptional. It not only occurs in the hairs of many other plants, as those of the Nettle and Glaucium luteum, but in the internodal cells and so-called leaves of the species of Chara and Nitella, in the leaves of Vallisneria spiralis, in the epidermal cells and hairs of the common Plantain, etc. It is, moreover, probable that the activity which in these instances is so conspicuous to the eye really exists to a less degree in the protoplasm of all living cells.

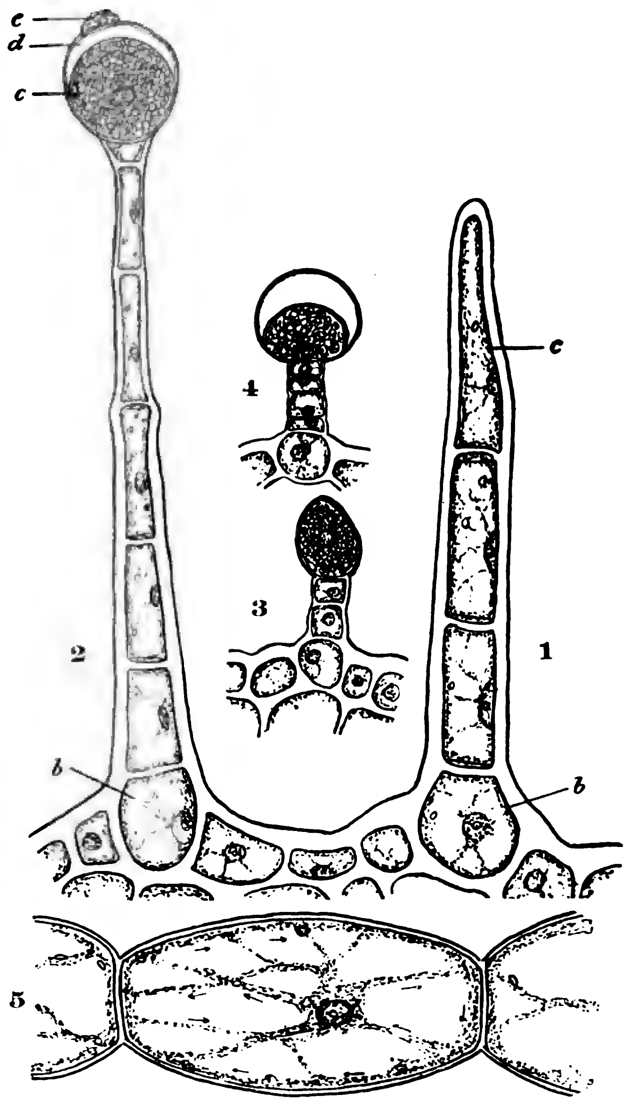


PLATE XLV.—Hairs from Stem of Pelargonium zonale and from Filament of Tradescantia Virginica:

FIG. 1.—A Simple Hair of Pelargonium: *b*, basal cell adjacent to ordinary epidermal cells; *c*, apical cell. Each cell contains protoplasm, a nucleus, and a few leucoplasts.

FIG. 2.—One of the Large Glandular Hairs of Pelargonium: *b*, basal cell; *c*, gland-cell containing densely granular protoplasm; *d*, oleo-resinous secretion between cuticle and the rest of the cell-wall; *e*, exuded oleo-resinous matter.

FIG. 3.—Another form of Glandular Hair from same plant, the gland-cell of which is usually oblong or ovate.

FIG. 4.—A third kind of Glandular Hair from same stem.

(Magnification of Figures 1-4, 330 diameters.)

FIG. 5.—Small portion of Staminal Hair from Tradescantia Virginica, showing currents in the protoplasm of the cell. The arrows indicate the direction of the currents. (Magnification about 300 diameters.)

EXERCISE VIII.

STUDY OF SUBEROUS TISSUE AND LENTICELS.

THE twigs of almost any woody gymnosperm or dicotyl, if of sufficent age, will afford good examples for study. The following list is one from which the student may make good selections: the White Willow (Salix alba, *L.*), the Oleander (Nerium Oleander, *L.*), the Apple (Pyrus Malus, *Tourn.*), the Bittersweet (Solanum Dulcamara, *L.*), the Basswood (Tilia Americana, *L.*), the Elder (Sambucus Canadensis, *L.*), the Chestnut (Castanea sativa, *Miller*, var. Americana, *Gray*), the Horseshoe Geranium (Pelargonium zonale, *Willd.*), the Balsam Poplar (Populus balsamifera, *L.*), the Locust (Robinia Pseudacacia, *L.*), the Honey Locust (Gleditschia triacanthos, *L.*), the Black Currant (Ribes nigrum, *L.*), and the Sycamore (Platanus occidentalis, *L.*).

I. CORKY TISSUE.—(1) The first selection for this exercise is the stem of the Horseshoe Geranium, which was also made the subject of Exercise II., Part II. Especial attention is now directed to the corky tissue. If the stem be carefully observed, it will be seen that the upper portion is bright-green in color, that a little lower down the green is giving place to a brownish color, and that still lower down the green color has quite disappeared. This is because in the older part opaque cork has been formed just interior to the epidermis, obscuring the chlorophyll-bearing cells beneath, while in the younger portions this cork has either not yet formed at all or its cells are still young and transparent. In order to understand the formation of the cork it will be necessary to study it in different stages of development. Let study first be given to cork-tissue which is fairly mature, by examining sections of a stem that is already brown at the surface. The cross-section will look like that shown in Exercise II. (Pl. XXXIX.). At the very outside is the cork, the epidermis with its glandular and other hairs having already been pushed off by the formation of the cork beneath it. The latter may consist of fifteen or twenty

tiers of cells which are thin-walled, four-sided, considerably longer in a direction parallel to the surface than in the radial direction, arranged in distinct radial rows and more or less distinctly in tangential rows also, the arrangement being so compact that no intercellular spaces are visible. The outer and older tiers of cells are often collapsed—that is, the walls have fallen together—and some of the cells are scaling off at the surface: these are the oldest cork-cells, the youngest being farthest interior. It will be observed also that some of the old cells are opaque from containing air and brownish coloring matters. The walls of the mature cells are also more opaque than those of the younger ones, and the radial walls are more wrinkled the older they are. These appearances belong to nearly all cork-tissue, and by means of them the tissue may readily be recognized.

If with the cross-section be compared a longitudinal one, it will be found that there is little difference in the appearance of the cork-tissue, the most noticeable being the slightly greater average length of the cells in longitudinal view.

(2) Let tests now be applied to determine the composition of the cork. Testing a section with zinc-chloriodide iodine, it is found that all the older cork-cells stain brown, while the very youngest ones show the cellulose reaction. The mature cells are then either cutinized or lignified, the choice being determined by means of another test: Preparing a new section and putting it on a slide, a few drops of concentrated aqueous solution of chromic acid are applied. Watching results closely, it is seen that after a few minutes only the older cork-cells remain, both the cellulose and lignified tissues having been disintegrated and destroyed. The cutinized epidermis would have behaved in the same manner with the same test, and it is concluded therefore that the cork-cells are, chiefly at least, composed of cutin. They are spoken of as *suberized*, but cork-substance or suberin is the same thing as cutin. To confirm the results obtained and to make certain that no mistake has been made, another test is applied: To a fresh section, on a slide, a few drops of a concentrated solution of potassium hydrate are applied: the cork-cells soon assume a yellow color, which, on warming the slide over a lamp, becomes more decided. This is also one of the characteristic reactions of cutinized and suberized tissues.

But still another test may be tried: To a fresh section a few drops of cold Schulze's maceration fluid are applied, and it will soon be found that the cork-cells have turned a yellowish-brown color. The slide is now heated over the lamp, and as evaporation takes place fresh portions of the liquid are supplied by running it under the edges of the cover-glass. Examining the preparation from time to time, it will be found that the other tissues gradually dissolve and disappear, while the cork-tissue resists the action much longer; but presently, if the heat be continued, yellow drops of an oily-looking liquid begin to be formed in the now swollen and distorted walls, and ooze out into the cells and on their surface. The oily-looking liquid is ceric acid, soluble in alcohol, ether, chloroform, and in dilute aqueous solution of potassium hydrate, but not in carbon disulphide. The test most conclusively proves that the walls are suberized.

Cork-cells also stain a yellowish-green color with methyl-green solution, while lignified cells stain blue-green, and cellulose ones scarcely at all; cork-cells do not stain with hæmatoxylin solution, while both cellulose and lignified tissues do; but care should be taken, in applying this negative test, that the sections are not acid, and, if they have been treated previously with alcohol, that they have been washed thoroughly before applying the stain, otherwise cellulose and lignified tissues may not stain, and so may be mistaken for cutinized tissues.

(3) To study the development of cork, sections must be taken from a younger portion of the stem. These sections are made as thin as possible, and are cleared by treating them with two or three drops of chloral-hydrate solution on a slide. In specimens of the right age will be found on the outside the epidermis, consisting of a single thickness of cells, having, as usual, the outer wall thickened and cutinized at the surface, and beneath it the first tier of collenchyma-cells in the process of division, very thin cell-walls having been formed across them in a tangential direction. This is the beginning of the cork-formation. The outer cells of the two tiers thus formed do not again divide, but mature into cork-cells, while the inner ones retain their activity and again divide. Of the two new tiers formed from one by this last division, it is again the outer tier that develops into cork, while the inner tier again undergoes division, and so the process goes on.

By a judicious selection of different sections from the same stem all the different stages of cork-development may be observed.

The inner layer of cells in which the division takes place is called the cork cambium, or *phellogen.*

It is not the case in all plants that the cork begins to be formed in the layer of cells immediately beneath the epidermis. In some instances it begins in the epidermis itself; in others a few or several layers beneath the epidermis; and in still others in quite deep-lying tissues. At the close of this exercise is given a drawing of a small portion of the cross-section of the stem of the Bitter-sweet, showing the cork. Here the formation began by a division of the epidermal cells, and proceeded interiorly until, in the specimen from which the drawing was made, the phellogen-layer has become the fifth from the surface. The cork is ordinarily formed *centripetally* as in the Geranium, but sometimes *centrifugally;* that is, the inner of the two cells produced by the division is the one that develops into cork, while the other remains meristematic.

Cork, it will be observed, is, like epidermis, an admirable protecting tissue. By reason of its physical properties and the absence of intercellular spaces it prevents excessive evaporation from the plant. It also, by virtue of its impermeability to water, prevents injury from parasitic organisms. Bacteria and fungi are thus excluded, to a large extent at least. It is for these reasons that the plant when wounded soon covers the wounded surface with a layer of cork, and even provides a corky covering to the leaf-scar before the leaf separates from the stem.

II. LENTICELS.—Attention has already been drawn to lenticels in the study of twigs, Part I. If there be made several thin sections transversely through the young and still green stem of the Sycamore, it will be found that in some instances the knife has passed centrally through one of these little lens-shaped epidermal swellings. If the crest of the lenticel has not been ruptured, there will always be found at this point a stoma, for lenticels always begin their formation immediately underneath the stomata. The formation of lenticels, in fact, precedes the formation of cork under the rest of the epidermis and initiates the latter process. The cell-division, when once begun, proceeds rapidly, and results in the formation beneath the epidermis of a mass of

loosely-arranged cells which press upon the latter, forcing it upward and finally rupturing it, and from the opening thus produced the spongy mass of cork-cells protrudes.

If the formation of the lenticel has but just begun, there will be found only the outer layer of collenchyma-cells in process of division; if well advanced, the whole of the collenchyma beneath the stoma will have become involved, and the collenchyma as such will have disappeared, the tissues of the lenticel having been formed from it by division of its cells. Above, in the outer part of the lenticel, are the rounded, loosely-arranged cells called *packing cells*, and interior to these, next the cortical parenchyma, is a meristem-tissue or phellogen looking quite like the generative layer which produces ordinary cork.

On either side of the lenticel proper are found the outer tiers of collenchyma-cells beginning to divide in planes parallel to the surface; this is the beginning of the formation of cork under the rest of the epidermis, the formation proceeding much as that already described in the Geranium.

The function of a lenticel appears to be that of supplying air to the intercellular spaces; for, although the walls of the cells when mature are cutinized, the cells differ from those of ordinary cork-tissues in having intercellular spaces.

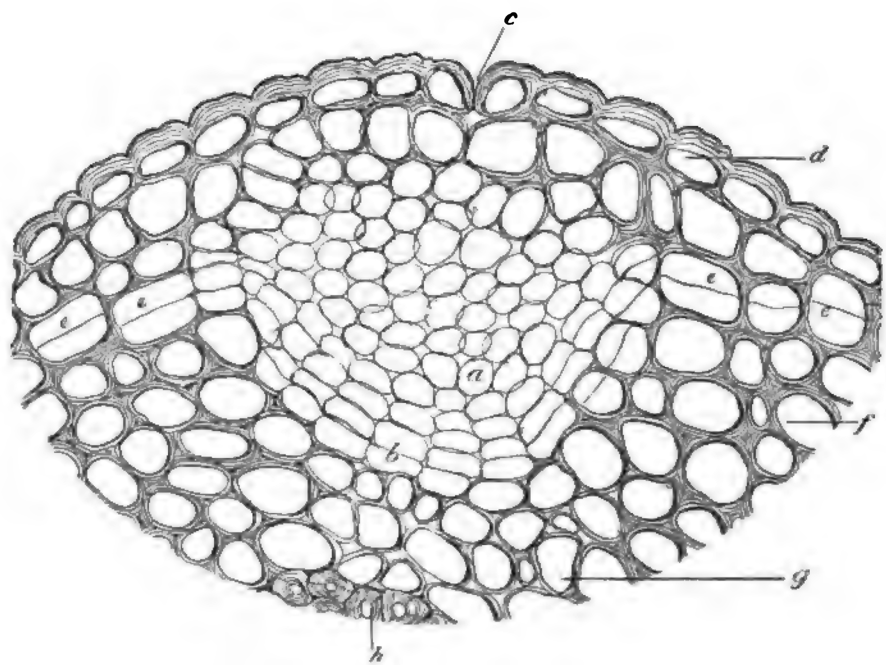
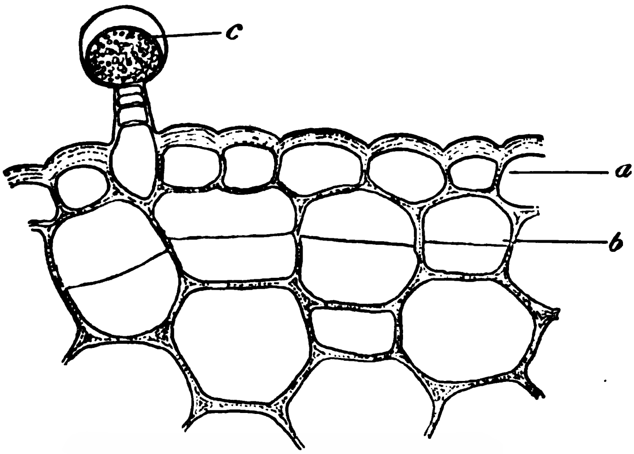
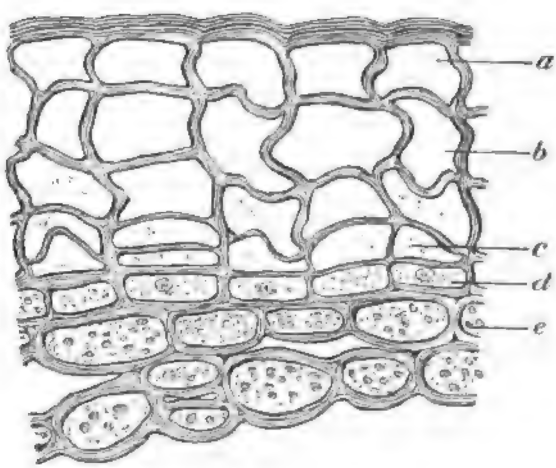


PLATE XLVI.—Lenticel of Platanus occidentalis, not quite fully formed: *a*, one of the packing cells; *b*, cork meristem or phellogen; *c*, stoma underneath which the lenticel has formed; *d*, epidermis; *e*, cell-division beginning for the formation of ordinary cork-cells; *f*, collenchyma-cell; *g*, parenchyma-cell; *h*, bast-fibre. (Magnification, 255 diameters.)



1



2

PLATE XLVII., FIG. 1.—A few Cells from the outer part of the young Stem of Pelargonium zonale, showing the beginning of the process of cork-formation: *a*, epidermis; *b*, collenchyma-cell immediately beneath the epidermis, one of a tier which has just divided (the outer of the two tiers is the young cork; the inner, the cork cambium); *c* is a glandular hair. (Magnification, 340 diameters.)

FIG. 2.—Transverse Section through Primary Cork of the Stem of Solanum Dulcamara (section made in early spring, from twig of previous year): *a*, epidermal cell converted into cork: *d*, cork cambium-cell: *c*, young cork-cell: *d*, older cork-cell; *e*, chlorophyll-bearing cell interior to cork cambium. (Magnification, 285 diameters.)

EXERCISE IX.

STUDY OF WOOD-CELLS OR LIBRIFORM TISSUE.

THESE terms include all those thick-walled, fibrous cells, not tracheary in their nature, which occur in the xylem of the vasal bundles of the higher plants, and also the similar fibrous elements which sometimes occur outside of the bundles altogether.

The term "libriform" has reference to the general resemblance the fibres bear to the liber- or bast-fibres often found in the inner bark of gymnosperms and dicotyls. The terms "liber-fibres" and "bast-fibres," as commonly used, are stretched to embrace all those fibres that occur in the phloem ends of vasal bundles, whether they occur in the inner bark or elsewhere in the plant, and whether they occur in gymnospermous and dicotyl plants or in monocotyls.

Libriform fibres differ usually from liber-fibres in being relatively less elongated, less tough and flexible, and less strongly thickened at maturity; but there are numerous exceptions, and in monocotyls particularly the tissues often so completely merge into one as to be wholly indistinguishable by their structure alone. Some authors include the two kinds of tissue under one head, and call them *sclerenchyma-fibres*. This mode of regarding them is convenient if the obvious distinctions between the two tissues as they exist in their more typical forms be not ignored.

While the writer cannot endorse the view that regards what has been called "sclerotic parenchyma" as more nearly related to sclerenchyma-fibres than to parenchyma, still, sclerotic parenchyma and sclerenchyma-fibres agree in the fact that both have lost their cellular character and have become purely mechanical tissues. Moreover, almost every gradation occurs between rounded stone-cells on the one hand and bast-fibres and wood-cells on the other: there are elongated and pointed stone-cells, and very short and thick bast-fibres that would be difficult to distinguish from each other. All of which proves that the hard and fast lines

drawn in classifications, useful and even necessary as they are, are lines which do not exist in Nature.

Libriform cells occur in great abundance in the stems of nearly all woody and many herbaceous dicotyls, in the region between the pith and cambium zone; in the meditullium of most woody roots of the same group; and in the stems and roots of many monocotyls and pteridophytes. It is unnecessary, therefore, to point out special examples for study.

The present study is made from the stem of Pelargonium zonale, the general structure of which is already more or less familiar.

(1) Several thin cross-sections are first made from a rather old stem, and, after placing those not required for immediate use in alcohol for future study, one of the sections is laid on a slide and treated with a few drops of the zinc-chloriodide iodine, covered, and examined. The wood which, along with other thick-walled tissues, forms a girdle about the pith is found to be stained a decided brown by the reagent—a reaction which, as already learned, is shown by lignified tissues. As a confirmatory test the phloroglucin reagent is applied to a fresh section and the same tissues are stained red. This lignification extends throughout the whole wall, but in the chloriodide-stained section the middle lamella is a little deeper brown and in the phloroglucin-stained one a considerably deeper red, so that this portion of the wall stands out with great distinctness. All of the cells in this region agree in the lignification of their walls; but some are medullary ray-cells, others ducts or tracheids, and still others are wood-cells. The ducts may mostly be distinguished in their transverse section by their larger calibre, but also, with care, by their markings, which may be seen by focusing up and down. The medullary rays may be distinguished by the fact that they occur in radial rows, are slightly elongated in a radial direction, and are of nearly equal size, while the wood-cells average smaller and are quite unequal in size and irregular in their arrangement.

In outline the wood-cells are irregularly many-sided or prismatic from mutual pressure during growth, and no spaces are discernible between them.

The reason why some cells appear much larger than others is

not because there is really so much difference in the actual size, but because they are pointed at the ends, and splice over each other in such a manner that in making a cross-section through the tissue different cells are cut at different levels—some through the middle, others near the ends.

A careful examination of the walls of the cells under a high power and with good illumination shows delicate concentric stratification-lines in the interior thickenings, and now and then very delicate pore-canals, though these are by no means so abundant as in the stone-cells which were studied.

If cross-sections of a young stem be compared with those of an old one, it will be found that in the former the wood-cells are much less thickened, and in a very young stem it will be found that the cell-walls are quite thin and wholly unlignified.

(2) Endeavor is now made to learn more about the cells by isolating them. This is accomplished by operating with Schulze's fluid on longitudinal sections in the manner directed in the study of stone-cells. The relation of parts will more satisfactorily be learned if the sections be cut with considerable care to get them directly lengthwise of the stem. They need not, however, be more than moderately thin. After treatment with the reagent they should be washed with care so as not to tear them, be stained with methyl-green, and then be placed in a drop of clean water on a slide, and covered. The cover is now gently tapped with a needle-point over the centre of the section. This, if not carried too far, and if the tissues have been treated precisely the right length of time in the macerating fluid, will cause the fibres to separate slightly, and yet they may be seen in nearly their natural relations to each other. It will then be observed how the wood-cells splice one over another as has been described.

The cells may now be separated still farther and the shapes of the wood-cells be studied more particularly. The fibres will be found to vary in length from three or four times as long as broad for the shortest ones to twenty or thirty times as long as broad for the longest ones, which attain a length of about one-twentieth of a centimetre. They mostly approach a fusiform shape, but the ends vary considerably, the cells sometimes being rather abruptly pointed at one or both ends and sometimes being forked or lobed. The sides are usually smooth, but sometimes,

where they fit against a row of medullary ray-cells, they are toothed or lobed.

The walls have no very conspicuous marks, but with good staining a considerable number of oblique slit-like pits may be seen, more transparent than the rest of the wall. If the high power of the microscope be focused on one face of the cell, the slits will appear to run, say, from the right obliquely upward to the left, but if it be focused upon the opposite wall they will seem to run obliquely upward from left to right. One may conclude from this and other observations that the markings are pits or thin places which lie along imaginary spiral lines winding about the walls, and the possibility is suggested that the thickening deposits have been made spirally as in some ducts. This view receives partial confirmation in the fact that when the cells are macerated until disintegration begins, they tend to separate into fragments spirally.

(3) How do the libriform cells of other plants compare with those of this plant? They agree, it may be answered, in general characteristics, but may differ in many minute details.

(*a*) They may be much thicker walled—in some of the harder woods so thick that the lumen may almost be obliterated. On the other hand, in many softer woods they may be considerably thinner walled.

(*b*) They may differ in size from those studied: they may be longer relative to their thickness, or they may average shorter. In these respects there may be considerable variations within the limits of the same species.

(*c*) The markings, pits, and pore-canals may be more numerous and conspicuous, or even less so, but they are never wholly absent. When the markings are conspicuous the tissue verges toward tracheary tissue, into which it passes by insensible gradations.

(*d*) Sometimes at maturity the wood-fibre does not represent a single cell, but a row of two or three cells which have united to form the fibre. Accordingly, one will occasionally meet with a fibre which contains one or two cross-partitions.

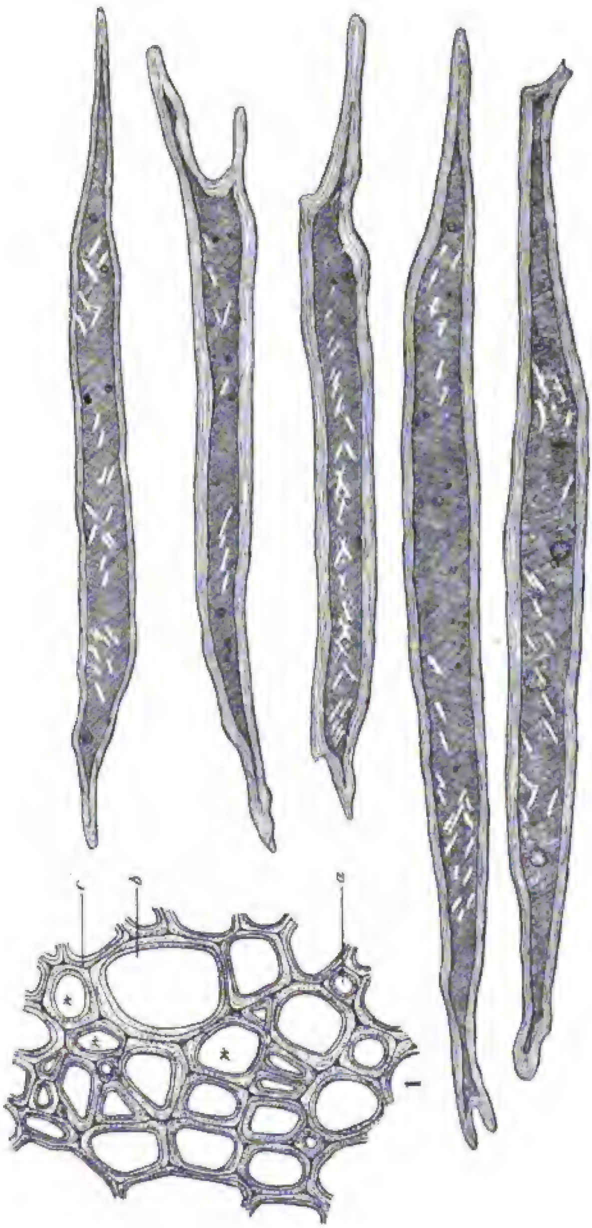


PLATE XLVIII., FIG. 1.—Small portion of Transverse Section of the Woody Zone of Pelargonium zonale (magnified about 535 diameters): *w*, *w*, wood-cells; *a*, a wood-cell which appears small because the section passes through it near one end; *b*, a duct; *c*, the middle lamella.

FIG. 2.—Five Wood-cells from the same plant, isolated by means of Schulze's process (magnified 285 diameters).

EXERCISE X.

STUDY OF TRACHEARY TISSUES.

UNDER this head are included tracheids and ducts. The former differ from wood-cells in the fact that their walls are less evenly thickened, and this gives rise to pitted, spiral, annular, ladder-like, or other conspicuous markings. Commonly also their walls are not so strongly thickened as are the wood-cells of the same plant, their calibre averages larger, and they are less tapering at the apex, sometimes merely oblique- or even blunt-ended; but these differences are not universal.

The distinction between tracheids and ducts is simply this: in the latter, two or more cells situated end to end have become confluent by the partial or total disappearance of the separating partitions, thus forming a tube or vessel sometimes of considerable length. Ducts usually average somewhat larger than tracheids in transverse diameter, but do not differ from them in their markings. Ducts are, in fact, at first thin-walled cells which in their development pass through the condition of tracheids; or a row of tracheids may be regarded as a duct arrested in its development.

Both ducts and tracheids occur in association with wood-cells in the xylem of vasal bundles. Tracheary tissues have even a wider distribution than wood-cells, being found in all vascular plants. There are few phanerogams or pteridophytes that do not contain at least two or three different varieties of tracheary tissue.

In the study of the wood-cells of Pelargonium in the last exercise attention must have been arrested by some of the varieties of tracheary tissue. Let the study of the xylem-tissues of this plant now be resumed, especial attention being given to the tracheary tissues.

(1) Among the wood-cells will be found some cells having a little wider diameter and more numerous, larger, and less slit-

like pits, but in other respects similar to those of which drawings were made in the last exercise. They are wood-cells that verge toward tracheids.

(2) There will be found other cells, with walls which look like an irregular network by reason of the numerous large pits. In these cells are to be found neither the remains of cross-partitions nor apertures communicating with adjacent cells. The pits are not in the nature of apertures, as one might suppose, but are very thin portions of the cell-membrane. This may be directly proved by means of the zinc-chloriodide iodine test or by staining with some diffusive stain, as eosin, as was done in the case of the pits in pitted parenchyma. These cells are reticulate tracheids, and are in their markings precisely like some of the ducts which occur abundantly in the same plant and associated with them. One of the tracheids is shown on Plate XLIX. (Fig. 1), and beside it (Fig. 2) a portion of a reticulate duct. Other kinds of tracheids with different markings may be found; but, since in their markings tracheids agree with ducts, the other varieties of tracheids will be passed by, and the remainder of this exercise will be devoted to the study of ducts.

Several different kinds of ducts may be found, but by far the most common in the older stems of this plant are the reticulate ducts.

(3) Attention will first be given to these reticulate ducts. The treatment with the maceration fluid usually results not only in the separation of the ducts from adjacent tissues, but in the separation of the cell-components of the ducts themselves, whereby may more easily be observed the perforations in the end partitions which distinguish the ducts from tracheids. These perforations are illustrated on Plate XLIX. (Figs. 2, 3, and Fig. 4, *a*). In this last the perforation is located in the oblique end of the cell. The walls are usually more or less prismatic from pressure against abutting cells, and it is in the flat sides that the thin places or pits occur. These pits are of the same essential nature as those already described in parenchyma- and wood-cells, and, like them, are means of keeping up a lateral circulation through the tissues.

In some instances it will be found that the component cells of the ducts are blunt-ended, in others that the ends are oblique,

and in still others that they are tapering, almost like wood-cells. Considerable variations in this respect occur even among the different cell-components of the same duct. The terminal cells in the series, however, are nearly always pointed.

Associated with the reticulate ducts are found some which, by reason of the quite regularly arranged pits elongated in a transverse direction, are more properly called *scalariform ducts*, so named because the markings appear somewhat like the rounds and spaces of a ladder. Between these and the reticulated forms there is every gradation, and sometimes there may be found a cell reticulated on one face and scalariform on another. Gradations also occur between reticulate and spiral ducts, as will presently be seen. More especial attention will be given to scalariform ducts in the next exercise.

(4) The next most widely distributed duct in vascular plants is perhaps the *spiral*. These ducts are especially abundant in that part of the wood nearest the pith. Their peculiarity consists in the fact that the thickenings consist of one or more spiral bands which wind, usually quite regularly, around on the inside of the cell-wall, the rest of the wall remaining quite thin, and even being difficult to recognize unless special means are employed to bring them into view. The reason is that the thin part is of cellulose, which does not stain with the methyl-green. Often the remains of the transverse partitions between the component cells are also difficult to recognize, especially as the spiral thickenings are continuous from cell to cell.

The spiral bands are very readily pulled out of the ducts, and in most sections in which these ducts occur the bands will be found partially drawn out of some of the ducts by the section knife in the process of cutting. When the petiole of a water-lily or that of almost any other petiolate leaf of a vascular aquatic plant is pulled asunder, the spiral threads are pulled out and may often be seen with the naked eye, appearing like delicate cobwebs.

The spiral ducts in most other species, as well as in this, average smaller in diameter than the reticulate and scalariform ones. They differ much among themselves, however, in this respect; they differ much also in the number and closeness of the spirals. In this plant both double- and single-spiraled forms are abundant:

those with a higher number of spirals are rare, but in some water-lilies as many as eight have been found in a single duct. In some, the spirals, whether single or double, are close, while in others they are distant. It has just been stated that connecting forms between spiral and reticulate ducts are sometimes found. Illustrations of this also are found in the Geranium; that is, in some instances thickenings run across and connect the neighboring turns of the spirals, and so form a more or less perfect network. If these thickenings are numerous, the spiral character is obscured and the duct acquires a decidedly reticulate appearance. Hence also, in searching through a quantity of material obtained by macerating a longitudinal section in Schulze's fluid, ducts will probably also be found that are distinctly spiral at one end and reticulate at the other.

In some cases a duct will at one end contain a single spiral, while at the other there is a double one; or the spiral may be double in the middle of the duct and single at each end.

(5) There is a close relation also between spiral and annular ducts. In the Geranium the two kinds are closely associated in the layer of the wood next to the pith. Annular ducts have all the general characteristics of spiral ones except that the thickenings form a series of rings instead of spirals, distributed along the length of the duct on its interior. These rings are sometimes close together, at others widely separated; sometimes they are placed with their plane at right angles to the axis of the duct, but often obliquely to it; and they may be at various inclinations in the same duct. The close relation between annular and spiral ducts is shown by the fact that a duct may at one end be annular and at the other spiral. A portion of a mixed duct of this kind is shown on Plate XLIX. (Fig. 8).

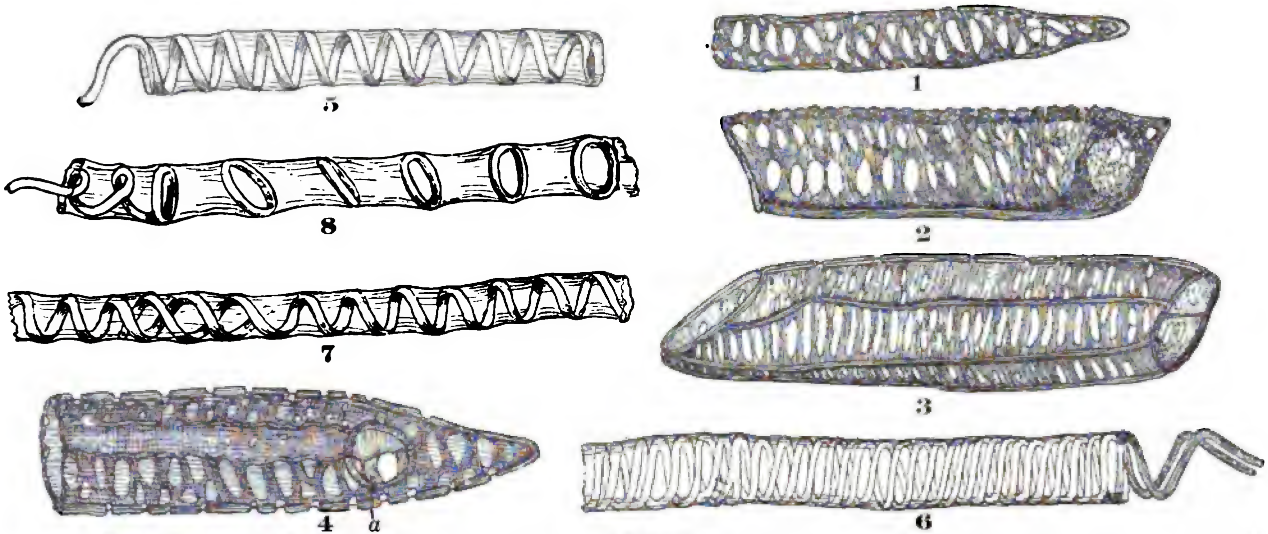


PLATE XLIX., FIG. 1.—A Reticulate Tracheid from the Stem of Pelargonium zonale. The section-knife has passed lengthwise through it near the middle. The unshaded portions are the thin places or pits in the walls.

FIG. 2.—One of the Cell-constituents of a Reticulate Duct from the same plant, also split lengthwise, and showing a large perforation in the oblique end-plate.

FIG. 3.—One of the Cell-components of a duct intermediate between the reticulate and scalariform varieties. The end partitions have entirely disappeared, but their position in the entire duct is marked by a constriction.

FIG. 4.—Part of a Cell of a Reticulate Duct, showing a rounded perforation, *a*, in the oblique end by which the lumen was continuous with that of the next cell in the series forming the duct.

FIG. 5.—Portion of one of the Spiral Ducts containing a single spiral.

FIG. 6.—Portion of one of the Spiral Ducts which has a double spiral.

FIG. 7.—Part of one of the Spiral Ducts, in one portion of which there are two spirals, and in the rest but one.

FIG. 8.—A portion of a mixed Spiral and Annular Duct.

(All the drawings are from the same plant, and all are magnified about 330 diameters.)

EXERCISE XI.

STUDY OF TRACHEARY TISSUES (CONTINUED).

(1) *The Scalariform Duct.*—There was observed in the study of the tracheary tissues in the Geranium stem a form of duct with transversely elongated pits, which duct was described as scalariform. These ducts occur also in many other dicotyls. Typical forms, however, are more readily found in some monocotyls, as in the roots of official Sarsaparilla, in Smilax rotundifolia, *L.*, and in other species of this genus, but especially in the rhizomes and petioles of some ferns, as Aspidium marginale, *Swartz*, A. Filix-mas, *Swartz*, and Pteris aquilina, *L.* In this last plant particularly the ducts are beautifully developed, and they constitute by far the larger proportion of the tracheary tissues of the plant. Beautiful preparations may be made by the following process: Cut the sections quite thin and accurately lengthwise of the vasal bundles. If the sections are made from fresh material, they should be passed through alcohol, transferred for fifteen or twenty minutes to a dilute aqueous solution of iodine-green, rinsed in water, passed through ordinary and then through absolute alcohol, soaked for a few minutes in the eosin oil of cloves, and mounted in xylol balsam. By this method all the lignified portions of the ducts will retain the green stain, while the thin membrane of the pits will have the red color of the eosin.

The ducts, it will be observed, are mostly prismatic, with several or many flat sides where they impinge against adjacent ducts or other tissues; the ends are either strongly oblique or taper-pointed, and where the ends of two of the component cells of a duct splice over one another the ladder-like thickenings usually remain, but the thin membrane between disappears. Each of the flat sides of the duct, if it impinges on another, is marked with the crowded, transversely-elongated, and regularly-arranged

pits which constitute the special characteristic of this form of tracheary tissue. Scalariform ducts are usually of large size.

Beautiful and very instructive preparations may also be made by means of the Schulze maceration process, if after the separation of the component cells they are stained by means of iodine-green.

Figure 1 (Pl. L.) shows a part of one of the ducts from the rhizome of Pteris aquilina.

(2) *The Pitted Duct.*—This duct is exceedingly common, especially among woody dicotyls, and is often called the *dotted* duct. It may be studied to advantage in the stems of any of the following plants: the Compass Plant (Silphium laciniatum, *L.*), Bitter Dock (Rumex obtusifolius, *L.*), the Pumpkin (Cucurbita Pepo, *L.*), the Butternut (Juglans cinerea, *L.*), the Walnut (Juglans nigra, *L.*), the Ailanthus (Ailanthus glandulosus, *Desf.*), the Oaks, and the Maples. Ducts of this kind are, like those just described, usually large, often, however, not very thick-walled in proportion to their diameter, and marked with numerous rounded pits which differ much in size, number, and arrangement in different plants. Between the typical forms with circular pits and those with pits transversely elongated so strongly that the ducts may be called scalariform there is every possible gradation.

The very large and complicated ducts found in the stem of the Pumpkin are selected for study in this exercise. It will be sufficient if thin longitudinal and transverse sections be stained with the zinc-chloriodide iodine.

In the transverse section the ducts appear as very large circular apertures in the xylem of the bundles, bounded by a rather thin but distinctly pitted, lignified wall which is backed by numerous small, thickish-walled, and pitted parenchyma-cells.

Under a high power the pits of the duct are seen to be somewhat lenticular spaces in the wall, with short canals connecting them with the interior and exterior faces of the wall. A fortunate staining of the longitudinal section with eosin or with carmine would show that the canals do not extend clear through the wall, but that the pits are still closed by a very delicate membrane—the so-called limiting membrane—the persistent middle lamella of this portion of the wall. They are therefore somewhat similar to, though much smaller and more difficult to study than, the

bordered pits in the tracheids of gymnosperms, presently to be examined.

In the longitudinal section are observed the pits crowded in irregular groups, the groups bounded off from each other by elevated unpitted ridges, so that the surface of the duct appears as an irregular network with numerous pits in the meshes.

The pits appear in this section as rounded or oblong areas, each with a minute circle, more transparent than the rest, in the centre. The rounded shape of this central thin portion of the pit is rather exceptional among dicotyls; this portion of the pit is more commonly elongated and slit-like in form.

(3) Let attention now be given to the tracheids of gymnosperms. Any species of Pine, Larch, Fir, Juniper, or Cypress will serve well the purposes of study. In these and most other gymnosperms ducts are rare, and so too are wood-cells; but tracheids, an intermediate tissue, take the place of both, and constitute nearly the whole of the wood of the plant. These tracheids have a structure so peculiar that it is an easy matter to tell a gymnospermous plant from any other by a microscopical examination of the wood.

For this study of tracheids is selected a twig of the Bald Cypress (Taxodium distichum, *Richard.*).

Sections are made in three different directions: (1) transverse, (2) longitudinal-radial, and (3) longitudinal-tangential. A longitudinal-radial section is one that passes lengthwise of the stem and through the centre or nearly so; that is, it is cut in the direction of, or along, the medullary rays. A longitudinal-tangential section is one that passes lengthwise of the stem, but near its circumference, and therefore crosses the direction of the medullary rays. It is of course important that both sections should be thin and be cut parallel to the grain. A straight-grained twig should therefore be selected for sectioning.

Let each of the sections be treated with the zinc-chloriodide iodine, and the longitudinal-radial section first be examined, using for the purpose the low power.

The tracheids will be seen as elongated fibres tapering usually at each end, and looking, except for their larger size and peculiar markings, much like ordinary wood-cells. The markings or bordered pits, as they are called, are large compared with those already

studied, though considerably smaller than those of many other Coniferæ. Each pit appears, in this view, as a circle with a much smaller concentric circle in its interior.

The pits are in one or two rows, but not evenly distributed along the length of the cells; in some places they are crowded, in others widely separated.

At intervals crossing the direction of the tracheids are short parenchymatous cells, but with thickened and lignified walls. These cells are arranged like the bricks in a wall. The mass constitutes a medullary ray.

In order that the nature of the pits may be the better understood, the longitudinal-tangential section is now studied. Here are found no markings on the sides which are presented to view, but only on the edges; that is, the disks occur on the sides which face toward the medullary rays, but not on those which face toward the exterior or toward the pith.

Moreover, in this view the pits do not appear round as before, but lenticular. Selecting a pit in which the section appears to have passed through the centre, let it be examined carefully with the high power. It will be found to show a structure like that represented in Figure 3 (Pl. LI.). There is a cavity shaped like a biconvex lens cut through the centre in the direction of the radii of curvature. At *b*, and also opposite on the other side of the lens-shaped area, are rounded apertures. It is one of these apertures which, when the disk is seen in the radial section, appears as the inner circle. At *a* is the thin membrane which divides the lenticular cavity into two parts. It is continuous with the middle lamella, *c*.

The pit, then, is a lens-shaped cavity situated in the common wall between two cells, crossed through its longer diameter by a delicate membrane, and perforated through its shorter diameter (except the membrane, which is continuous) by a circular aperture.

The medullary rays in this view present an appearance very different from that in the radial section, appearing as a row of from three to five rounded cells.

In transverse section the pits, of course, look as they do in the longitudinal-tangential section. The tracheids in this view appear squarish, and on the radial face of the walls are observed the

pits. The medullary rays in this section appear still different, the cells being elongated and forming a row which often extends from the pith to the outer limits of the wood.

(4) The rarest of all forms of markings found in tracheids and ducts is that called the *trabecular*. Its peculiarity consists in the fact that the thickenings, instead of being on or in the cell-wall, extend across the lumen of the cell. These thickenings, as in the other cases studied, are lignified, while the remainder of the cell-wall is usually of cellulose. Tracheids of this type occur in the leaves of the Juniper and in those of some Cycads.

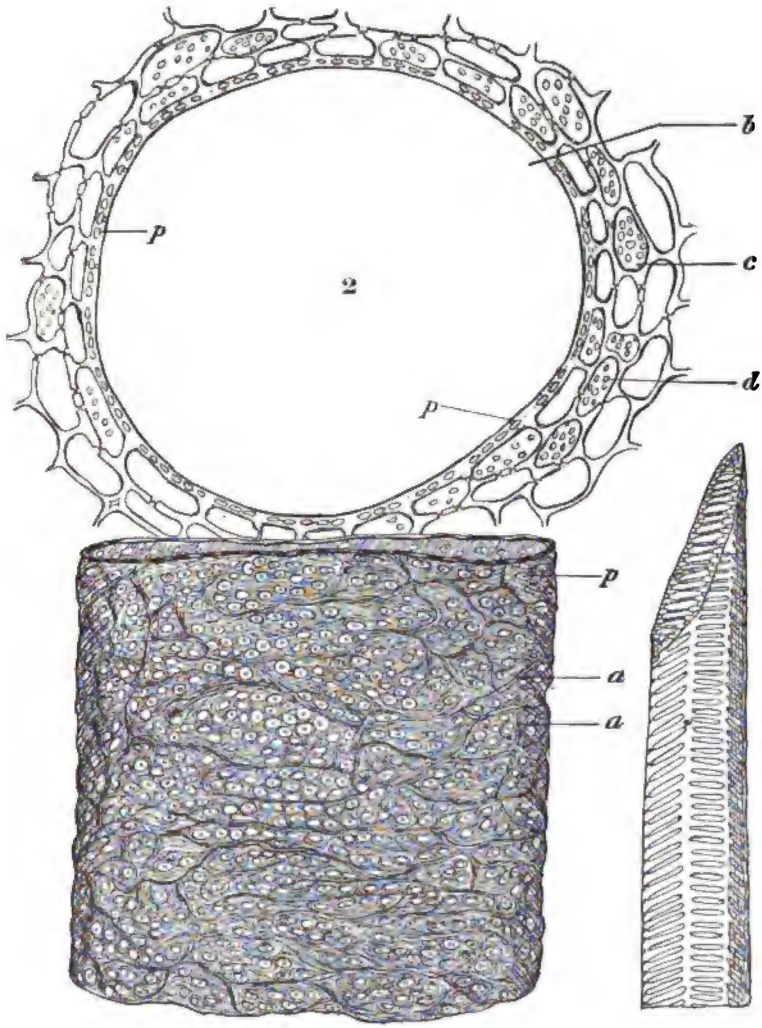


PLATE L., FIG. 1.—Portion of a Scalariform Duct from the underground stem of Pteris aquilina (magnification about 275 diameters).

FIG. 2.—Transverse Section of large Pitted Duct and a few adjacent Parenchyma-cells from the stem of Cucurbita Pepo: *b*, lumen of the duct; *c*, an adjacent parenchyma-cell with pitted walls; *d*, one of the pits; *p*, *p*, pits in wall of duct. (Magnification about 375 diameters.)

FIG. 3.—Longitudinal View of a small portion of one of the same Ducts, showing the pits grouped in the meshes of a network of ridges, *a*, *a*. *p* is one of the pits.

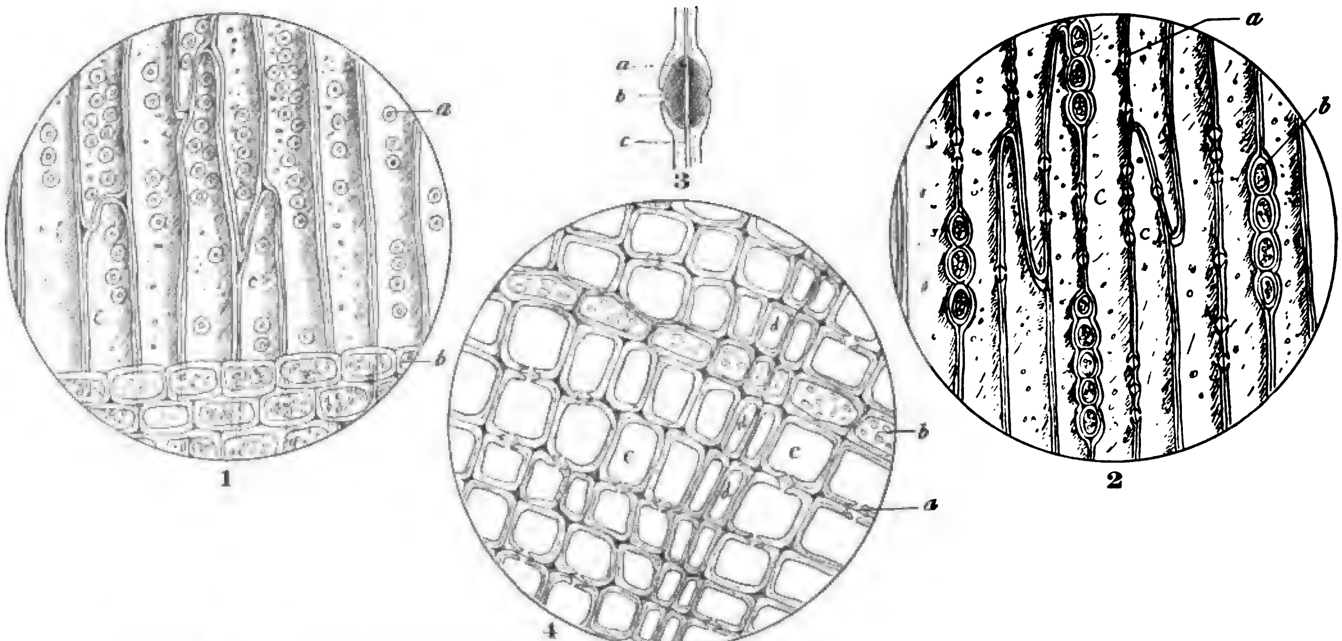


PLATE LI., FIG. 1.—Longitudinal-radial Section of a Twig of the Bald Cypress, showing tracheids with bordered pits: *a*, one of the pits; *b*, medullary-ray cell. (Magnification about 200 diameters.)

FIG. 2.—Longitudinal tangential Section of the same Twig, showing the pits in a different view: *a*, one of the pits; *b*, one of the cells of a medullary ray; *c*, *c*, tracheids. (Magnification also 200 diameters.)

FIG. 3.—A small portion of Wall, containing a pit much more highly magnified to show its structure: *a*, limiting membrane; *b*, aperture in pit; *c*, middle lamella.

FIG. 4.—Transverse Section of same Twig (magnified about 250 diameters), showing, *a*, one of the pits; *b*, a medullary ray; *c*, *c*, tracheids; *d*, *d*, narrower tracheids lying in a zone called a ring of growth.

EXERCISE XII.

STUDY OF BAST-FIBRES.

BAST- or liber-fibres are found, as has already been stated, in the inner bark of a very large number of dicotyls and gymnosperms, but they are absent from some, especially from many succulent and aquatic species. They frequently occur also in the phloem portion of the leaf-bundles of the same groups and in the phloem of the stems and leaves of some monocotyls.

Convenient examples for the student to investigate are the stem-barks of the following plants: the Yellow Cinchona (Cinchona Calisaya, *Weddell*), the Mezereon (Daphne Mezereum, *L.*), the Yellow Parilla (Menispermum Canadense, *L.*), the Slippery Elm (Ulmus fulva, *Michx.*), the Elder (Sambucus Canadensis, *L.*), the Compass Plant (Silphium laciniatum, *L.*), the Basswood (Tilia Americana, *L.*), the Umbrella Tree (Magnolia Umbrella, *Lam.*), the Bald Cypress (Taxodium distichum, *Richard.*), the Tamarack (Larix Americana, *Michx.*), and the European Larch (Larix Europea, *DC.*).

(1) Excellent examples of very typical bast-fibres are found in the stem of the Compass Plant. Attention will first be given to these. Having made a few thin longitudinal and transverse sections, they may be studied by aid of the phloroglucin reagent, when they will be stained red, the middle lamella more distinctly than the rest; or, better, they may be studied by the following process: Having passed the sections through alcohol, they are rinsed in water and are stained first with a weak solution of iodine-green, in which they are permitted to lie about twenty minutes; they are again rinsed slightly in water, and transferred to weak, then to stronger, and finally to absolute alcohol, until anhydrated; they are then placed in the clove-oil solution of eosin and allowed to remain fifteen or twenty minutes, and are finally mounted in xylol balsam.

Examining now one of the transverse sections, the cells are found to be closely pressed together so that no intercellular spaces are visible. The cells are observed to be polygonal in shape, much like the wood-cells already studied. In size the cells also appear quite different from each other—a fact which was observed in the study of wood-cells, and one which is susceptible of the same explanation—namely, that the section knife passed through some cells near the middle and through others near the attenuated ends.

The walls are not stained the same color throughout, but three distinct regions in them are discernible: the middle lamella, which is deep green; a thick portion next interior to this, also stained green, but of a different shade, usually lighter, and which is marked with numerous delicate concentric stratification-lines; and, lastly, a much thinner interior portion, not green at all, but red or reddish from having taken up the eosin stain, while the green was either not retained or was retained to but a slight extent. This portion, therefore, is not yet lignified, but is composed of cellulose chiefly; it is manifestly the youngest portion of the thickened wall.

Careful focusing with the high power will also show delicate straight tubes running from the lumen of one cell to that of another, interrupted, however, by the middle lamella. These tubes are the already familiar pore-canals.

Turning now to the longitudinal section, the fibres are here seen to be put together much as wood-cells, splicing one over the other by their attenuated ends, and forming a very tough and strong tissue. In shape they resemble wood-cells, but they are relatively somewhat longer and thicker-walled. Their length will be found to be as many as forty or fifty times their thickness. The fibres do not all represent single cells. In some cross-partitions may be seen, showing that a fibre is occasionally at least the product of two or more cells.

With care, if the section is thin, the pore-canals and stratification-lines may be seen; but here the former often look like dots instead of lines or tubes, for reasons already explained in the study of stone-cells.

It would also be found profitable to remove the bark from a part of the stem and to isolate the fibres by means of Schulze's

fluid, staining them afterward with iodine-green. The transverse partitions will thus the better be seen, and perhaps also some fibres will be found that are somewhat branching or forked at their ends.

(2) For branching fibres, however, the inner bark of the European Larch is more favorable for study.

Longitudinal sections of the bark are made and are treated with Schulze's maceration fluid; after washing, the tissues are teased apart with needles, are stained with the solution of methyl-green or with that of iodine-green, and are then examined. The fibres are found to be relatively shorter than those of the Compass Plant—many of them so short as closely to resemble stone-cells in appearance; most of them have the walls so excessively thickened that in places the lumen is wholly obliterated; and while the majority of the fibres are fusiform in shape and unbranching, a considerable number may be found that are variously lobed, forked, or branched. An occasional fibre will also be found that has a relatively large lumen or whose wall is but little thickened. In other respects there will be found but little difference between branching fibres and those already studied.

In the typical bast-fibre the lignification of the wall is not nearly so strong as that of the wood-cell or that of the tracheid or duct, though the thickening is usually excessive. In many cases, therefore, the coloration by means of the phloroglucin reagent is but slight, or even in some instances there is no color at all. This is particularly true of the long and tough fibres, such as those in Flax and Hemp, that are so extensively employed in the production of textile fabrics. Perhaps the fact of their being but slightly lignified accounts for their flexibility and tenacity. Very strongly lignified fibres, at any rate, are apt to be harsh and brittle.

(3) At the other extreme from the fibres of Flax and Hemp, so far as their structure is concerned, are the very short and thick fibres of the Cinchonas.

To study these a fragment of the bark of Cinchona Calisaya may be soaked in water for twenty-four hours and then be sectioned, a series of both longitudinal and transverse sections being made. The latter are bleached by soaking them in Labarraque's

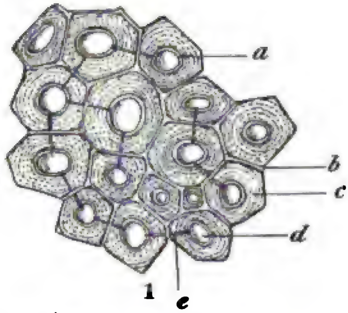
solution until the brown color disappears; they are then washed thoroughly in water to get rid of the last traces of the bleaching solution, and are stained with iodine-green. The bast-fibres occur either as isolated cells or as clusters of two or three scattered without much regularity through the inner bark. They are excessively thickened and strongly lignified, the lumen being in many instances almost obliterated. They are also of large diameter for bast-fibres. The thick walls usually show three distinct strata, each of which is subdivided into numerous delicate lamellæ. The pore-canals also, though not very numerous, are quite distinct.

If the microscope is provided with a polariscope, there will be found here an excellent illustration of the fact that thickened cell-walls often beautifully polarize the light which passes through them, so that when the Nicol prisms of the polarizer are crossed the fibres show brilliant color-effects. These effects are due to a difference of tension in the different lamellæ composing the cell-wall.

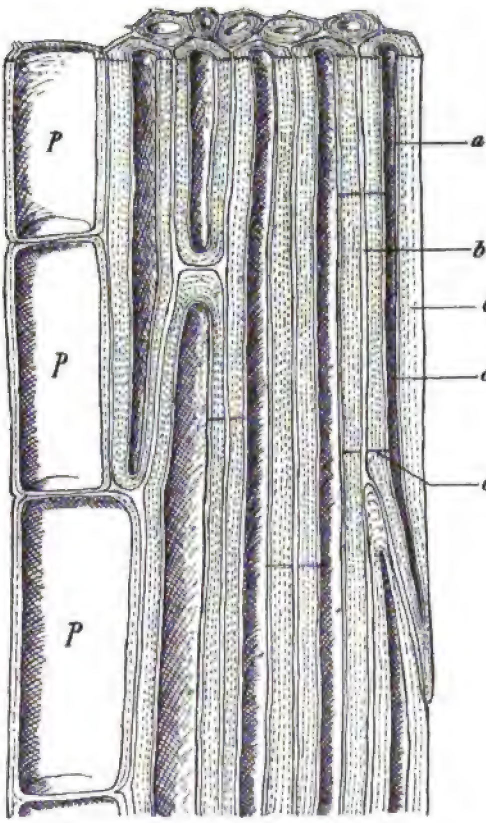
The longitudinal sections of Cinchona are treated in the usual way with Schulze's fluid to isolate the fibres. It will be found on staining and examining them that for bast-fibres they are excessively short, their length averaging perhaps not more than five or six times their thickness, and in some cases even they might easily be mistaken for stone-cells. They are acute, rounded, or wedge-shaped at the ends, seldom or never lobed or branching, and harsh and brittle rather than tough. If the bast-fibres of different plants were arranged to form a scale, with the shortest and thickest at one end and the longest and most flexible at the other, at or near the former extreme would be found the fibres of the Cinchonas; at the latter, those of Mezereum and Flax; while those of the Compass Plant would be found somewhere near the middle.

Indistinguishable in form and structure from bast-fibres are many of the sclerenchyma-fibres found altogether outside of vasal bundles, such, for example, as the strengthening fibres beneath the epidermis in some leaves, and the fibres which occasionally occur in the fundamental tissues of the cortex in many vascular cryptogams and in some flowering plants. Associated with bast-fibres are often found elongated, thick-walled, blunt- or

square-ended cells that differ from the bast-fibres only in their shape. They are sometimes called rod- or staff-cells. With these are also frequently associated ordinary stone-cells, and between the latter and the former may occur every possible gradation.



1



2

PLATE LII., FIG. 1.—Transverse Section of a few Bast-fibres from the inner bark of Silphium laciniatum (magnified 830 diameters): *a*, inner unlignified or only partially lignified portion of thickened wall; *b*, middle lamella; *c*, middle portion of wall; *d*, lumen; *e*, pore-canal.

FIG. 2.—Longitudinal Section of Bast-fibres of Silphium laciniatum (magnified 830 diameters). The letters *a*, *b*, *c*, *d*, and *e* refer to the same things as in the transverse section; *p*, *p*, *p*, adjacent parenchyma-cells.

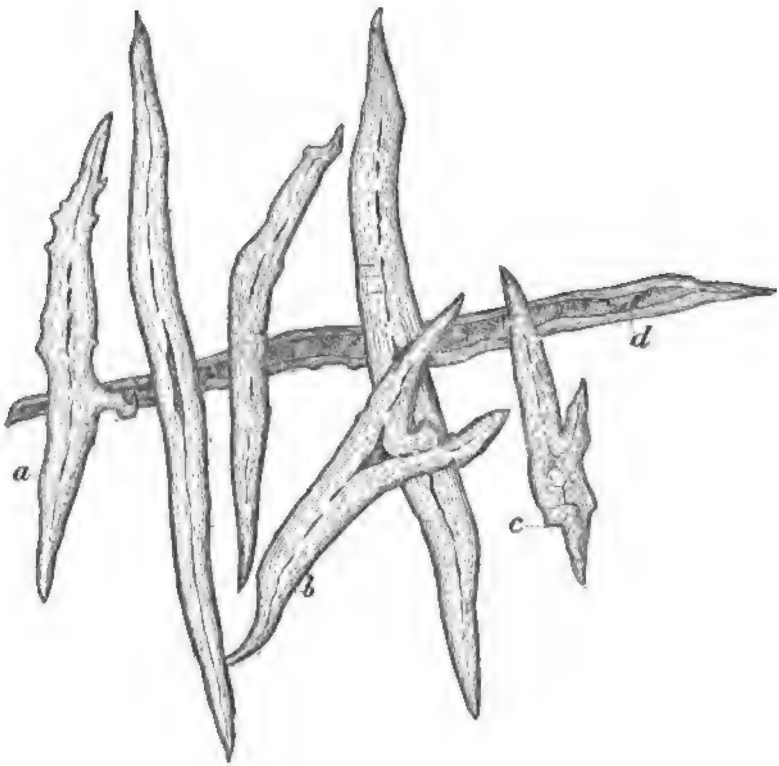
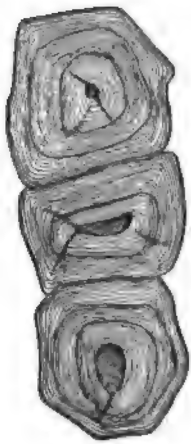
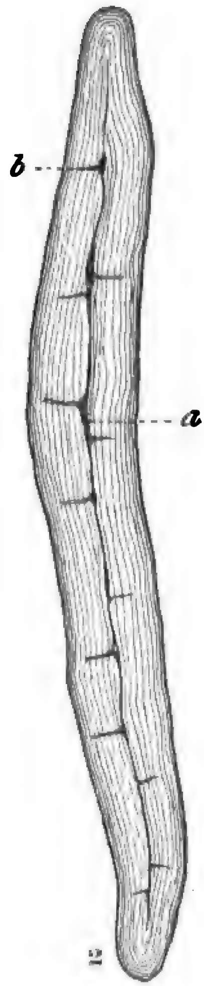


PLATE LIII.—Secondary Bast-fibres from the inner bark of Larix Europæa (magnified about 80 diameters): *a*, *b*, *c*, branching fibres, the last approaching a stone-cell in form; *d*, an exceptional fibre with a relatively large lumen. The fibres from which the drawings were made were isolated by means of Schulze's fluid.



1



2

PLATE LIV., FIG. 1.—Transverse Section of a cluster of three Bast-fibres from the inner bark of Cinchona Calisaya, showing strata, lamellæ, and pore-canals. (Magnified 340 diameters.)

FIG. 2.—View of a Bast-fibre from the same bark, isolated by means of Schulze's fluid (the fibre is rather longer than the average): *a*, the narrow lumen; *b*, one of the pore-canals. (Magnification, 210 diameters.)

EXERCISE XIII.

STUDY OF SIEVE-TISSUE.

SIEVE-TISSUE occurs in the phloem of vasal bundles, very rarely elsewhere in the plant. It constitutes the most characteristic tissue of the phloem, and it is nearly always associated with narrower, elongated parenchyma-cells called "companion-cells." Sieve-cells are almost always considerably elongated in the direction of the length of the vasal bundles in which they occur; their walls are thin and unlignified, but possess in certain parts, usually in the end partitions, more or less thickened plates with numerous minute sieve-like perforations through which proteids and other colloids in the semi-liquid form may circulate from cell to cell of the tissue.

The tissue in most plants, owing to the small diameter and thin walls of the cells and the minuteness of the perforations in the plates, is not an easy one to study, but favorable examples are the following: the stems of the Pumpkin (Cucurbita Pepo, *L.*), the Squash (Cucurbita maxima, *Duchesne*), the Watermelon (Citrullus vulgaris, *Schrader*), and the Hop (Humulus Lupulus, *L.*); the petiole of the Grape (any of the commonly cultivated species); the inner bark of the Slippery Elm (Ulmus fulva, *Michx.*) and the Basswood (Tilia Americana, *L.*); and the rhizome of the Mayapple (Podophyllum peltatum, *L.*).

The sieve-tissue of the Pumpkin will be studied in this exercise, and the preference is given to material which has been preserved in alcohol. Several sections, both longitudinal and transverse, are made, taking care that the former pass lengthwise of one of the vasal bundles in a radial direction, or at least through the phloem portions of a bundle. Several sections may have to be rejected before one is found that will show the tissue to the best advantage.

(1) Treat one of the transverse sections with the phloroglucin reagent, cover it, and examine it with the low power. It will be

observed that there are ten vasal bundles arranged in two circles about the central hollow in the stem. Each of the bundles consists of a xylem mass containing several large ducts as well as many smaller ones, which are stained red by the reagent, and two masses of phloem which are wholly unstained, one facing outward or away from the central hollow, the other toward it. The bundles of the inner circle are the larger, and are usually the more favorable for study.

Having brought a phloem part of one of these bundles to the centre of the field of the microscope, the high power is turned on and the structure is examined. The phloem will be found to be composed mainly of two kinds of cells, one kind rather large, the other much smaller, and all without visible intercellular spaces. The larger cells are the sieve-tubes; the smaller cells are the companion-cells or other intermixed parenchyma-cells. Many of the sieve-cells appear empty because the cells are long and the section has passed between the sieve-plates, which in this case are in the end partitions of the cells; but in some cells will be observed the plates, and unless they are placed too obliquely to the plane of vision there will be seen the numerous delicate apertures in them. These apertures may be empty, or they may be partially, or sometimes completely, filled with albuminous matters and a peculiar thickening substance called *callose*, so that they appear darker than the adjacent wall-substance.

If one of the sections be stained with strong potassium-iodide iodine, there will be found plates whose meshes are deep-brown from the proteids they contain, while the cellulose wall-substance is unchanged in color. The companion-cells are seen to be very rich in proteid matters.

(2) Let now a longitudinal section which has been treated for a few minutes with eosin solution be studied. This solution stains the proteid contents of the sieve-tubes strongly, and so enables one to identify the tissue. These proteids will have been shrunken by the action of the alcohol, so that they do not nearly fill the sieve-tube except in the vicinity of the plate, where they are usually denser and more abundant. Here, however, it will often be found that the shrinking effect of the alcohol has drawn the mass slightly away from the plate, pulling out more or less, so that they may be seen distinctly, the fine threads of

albuminous matter that penetrate its meshes and connect it with that of the next cell.

The companion-cells, though elongated, are much shorter than the sieve-cells, their ends are square or oblique, and their protoplasm is nucleated. In the common wall between these cells and the sieve-tubes will be found minute pits, but no perforations.

Now let there be examined a longitudinal section that has been treated for twenty minutes or more with a weak watery solution of anilin-blue, and mounted either in glycerin or in the chloral-hydrate solution. If mounted in glycerin, the best staining results will be obtained if the section be allowed to remain an hour or more in the glycerin before examining it. Most of the color will then have disappeared from the cell-walls, but will remain in the protoplasm and nuclei of the companion-cells and in the albuminous matters of the sieve-tubes, and the deposits of callose in the pores and on the surface of some of the sieve-plates will be stained a fine blue color somewhat different in tone from the rest, so that they may readily be recognized.

If desired, satisfactory permanent mounts may be made by carrying the sections, after staining, through weak into strong glycerin, and finally enclosing them in glycerin gelatin.

Another method which yields good results is as follows: Wash out the glycerin with water, anhydrate by passing the sections successively through weak, strong, and absolute alcohol, then through oil of cloves tinted with eosin, and finally mount in xylol balsam. By this means the slimy albuminous matter in contact with the sieve-plate acquires a tint different from that of the callus, rendering it easier to distinguish the one from the other.

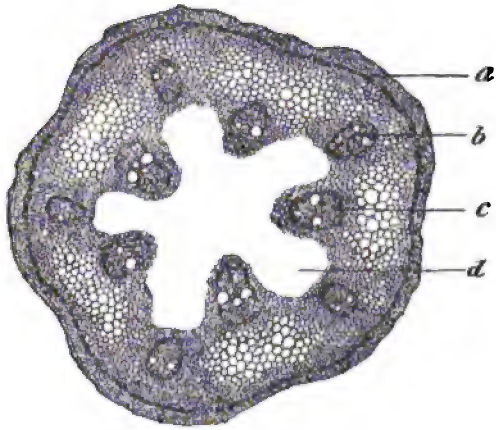
Satisfactory but more fugitive results are obtained by means of the anilin-blue and the chloral-hydrate solution. After staining with the blue the sections are mounted in the chloral-hydrate solution. The color very rapidly disappears from the cell-walls, but rather slowly from the other parts; at the same time the swelling of the walls and the clearing which the solution produces are of advantage in studying the structure.

Sieve-tissues appear to be an important means of transferring proteid nutriment from one part of the plant to another. The slimy, albuminous matters in the interior of the tubes do not appear to be protoplasm, but to be other proteinaceous material

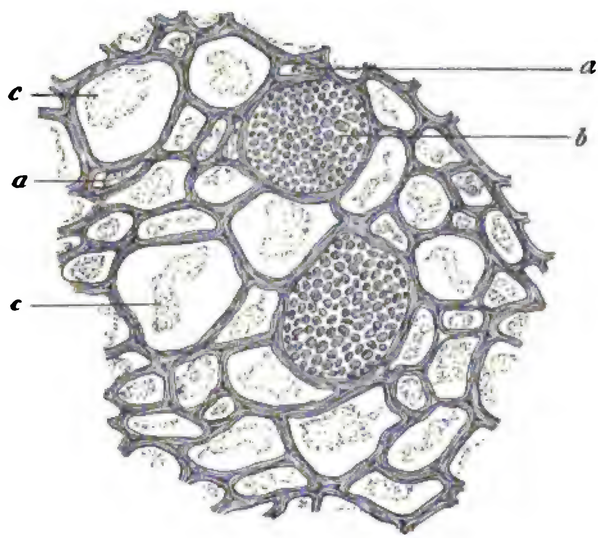
in the process of transfer. The sieve-cells, however, are probably still living cells, for it has been found that the wall is lined with a delicate layer of protoplasm, but a nucleus has not been discovered in them.

The callose of sieve-tubes is something related to, but somewhat different from, cellulose. That it is not identical with cellulose is evident not only from the fact that it stains much more strongly with anilin-blue and corallin, but also from the fact that it is wholly soluble in 1 per cent. potassium-hydrate solution, while cellulose is not.

Callose is not confined to sieve-tubes, but occurs in the hyphæ of some fungi, in certain pollen-grains, in the seeds of certain of the Borraginaceæ, and associated with calcium carbonate in cystoliths and in certain encrusted cell-walls.



1



2

PLATE LV., FIG. 1.—Transverse Section of Pumpkin stem (magnified about 5 diameters): *a*, sclerenchymatous ring in cortex; *b*, one of the outer circle of vasal bundles; *c*, one of the inner circle of bundles; *d*, central pentagonal hollow.

FIG. 2.—Transverse Section of a portion of the Soft Bast of Pumpkin stem (magnified 210 diameters): *a*, *a*, companion-cells; *b*, sieve-plate of sieve-tube; *c*, *c*, sieve-tubes cut through between the plates so that the latter are not shown.

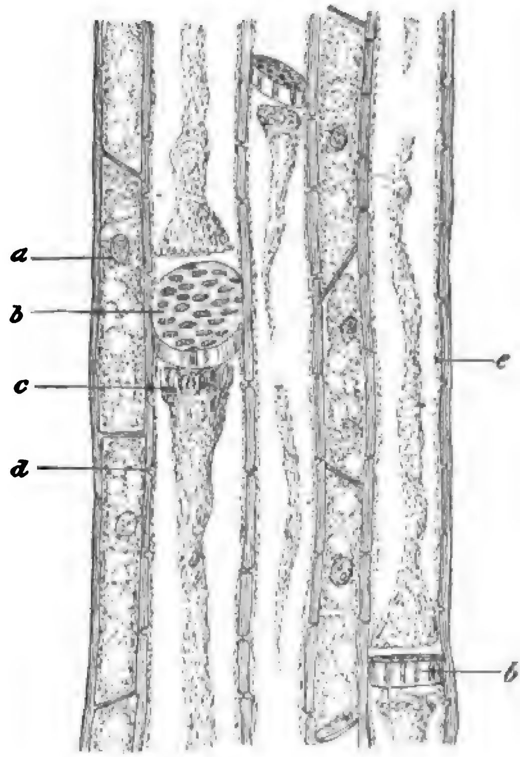


PLATE LVI.—Longitudinal Section of the Soft Bast of Pumpkin stem (magnified 210 diameters): *a*, nucleus of companion-cell; *b*, *b*, sieve-plates; *c*, albuminous matter shrunken away from plate by action of alcohol; *d*, pit in lateral wall of sieve-tube; *e*, thin layer of protoplasm lining sieve-tube.

EXERCISE XIV.

STUDY OF LATICIFEROUS TISSUE.

THERE are two principal kinds of milk- or laticiferous tissue —the simple, and the complex or articulated. For the study of the former kind selections may be made from the following objects: the stem of the common greenhouse plant Euphorbia splendens; the root of the Flowering Spurge (Euphorbia corollata, *L.*); the stem and root of the Common Milkweed (Asclepias cornuti, *Decaisne*); the stem and root of the Purple Milkweed (Asclepias purpurascens, *L.*); the stem and root of the Dogbane (Apocynum androsæmifolium, *L.*); the stem and root of the Canadian Hemp (Apocynum cannabinum, *L.*); the stem of the Fig (Ficus Carica, *L.*); and the stem of the Oleander (Nerium Oleander, *L.*).

For the study of complex laticiferous tissues selections from the following objects may be made: the root of Dandelion (Taraxacum officinale, *Weber*); the root of Chicory (Cichorium Intybus, *L.*); the stems of Wild Lettuce (Lactuca Scariola, *L.*, and *L.* Canadensis, *L.*); the stem and root of Celandine (Chelidonium majus, *L.*); the stem and young capsule of the Opium Poppy (Papaver somniferum, *L.*); the root of Spanish Salsify (Scorzonera hispanica, L.); and the root of Common Salsify (Tragopogon porrifolius, *L.*).

I.—For the study of *simple laticiferous tissue* there is selected from the former list the stem of the common Milkweed.

In the study of laticiferous tissue of any kind the parts of the living plant to be investigated should be cut into pieces, not too small, and immediately be dropped into strong alcohol and there allowed to remain until the liquid has thoroughly penetrated the structure. The object of this treatment is to coagulate the latex before it has had time to escape from the vessels, so that the course of the latter may the more readily be traced.

Having thus prepared the material, thin transverse and longi-

tudinal sections are made and stained, some of them by means of the iodine-green solution. To one or two of the remaining sections of each kind are added a few drops of zinc-chloriodide iodine, and they are set aside for a while until the cellulose walls have acquired the blue color.

Placing one of the green-stained transverse sections under the microscope and examining it with the low power, the milk-tubes may be seen in abundance in the pith and in the middle and inner bark. In the pith and in the middle bark they may readily be recognized by the fact that they are narrower than the adjacent parenchyma-cells, by their more densely granular contents, and by the absence of a nucleus. It will also often be found that their walls are somewhat thicker than those of the parenchyma-cells, particularly if the section be that of a well-matured stem. This difference will be noticeable particularly in the pith and soft bast if to an unstained section a few drops of chloral-hydrate solution be applied.

Moreover, the razor in passing through the tissue frequently draws the elastic and extensible masses of latex more or less out from the tubes, thus aiding in the identification of the tissue. The latex appears opaque and densely granular as viewed by transmitted light.

Turning now to one of the green-stained longitudinal sections, and having identified the laticiferous tubes with the low power, let them be studied minutely with a higher one.

There will be but little difficulty in tracing the tissue by aid of the coagulated latex for considerable distances through the stem, for the latex-cells form tubes of indefinite length. While their general course is lengthwise of the stem, they are nevertheless somewhat wavy or serpentine, though less so in this species than is often the case in other plants. The tubes do not branch freely, although they do so occasionally, and very rarely are the branches of one tube observed to anastomose with those of an adjacent one.

For these reasons, and because the tube with its branches is believed to represent a single cell, even though it may run the entire length of the plant, this variety is called "simple laticiferous" tissue. Wherever it occurs its structural features are essentially similar to those observed in this plant.

Removing this section now, and substituting for it a set of sections which have been treated with the zinc-chloriodide iodine, it will be found from the blue stain that the walls of the tubes are of cellulose.

From the brown color which the iodine has communicated to the latex it is also concluded that the latter contains proteid matters. Starch is not found in the latex of this plant either by means of this test or by that of the chloral-hydrate iodine, though it occurs in the latex of some other plants—for example, in that of Euphorbia splendens, where the grains are rod-like, clavate, or dumb-bell-shaped.

That the latex contains oily or oleo-resinous matters is sufficently evidenced by the fact that it stains deep-red with the alcannin solution. It is the presence of these matters, emulsified by aid of the albuminous and mucilaginous substances also present, that gives to the fluid its milky appearance.

The last test applied also reveals the presence in the latex of other bodies—solid angular particles, often of considerable size, which do not take up the stain. On testing them with potassium-hydrate solution they remain unaffected, as they do also when treated with acetic acid; but on testing them with hydrochloric acid they disappear without effervescence. It is concluded, therefore, that they are composed of calcium oxalate. They do not appear to be present in all of the latex-tubes, though they are rather abundant in some.

II.—*Complex laticiferous tissue* will now be studied as it is found in the root of the Common Dandelion. The peculiar distribution of the milk-tissue in the cortex has already been observed in the study given to this root in Part. I.

Several sections, longitudinal and transverse, of alcoholic material are made, and one of each kind is stained with iodine-green. The latex stains strongly, and so permits the ready identification of the tissue.

Focusing first with the low power on one of the circles of milk-vessels in the transverse section, it will be found that the vessels occur in clusters of various sizes, and that these clusters are so arranged as to form a series of circles one within the other. These circles, each appearing to the naked eye continuous, give to the bark of this root its concentrically stratified appearance. The

circles occur both in the middle and in the inner bark, but not in the wood.

Under a high power the milk-ducts appear to be of considerably smaller diameter than the neighboring parenchyma-cells. Most of them appear circular or oblong in outline because the knife has cut the cylindrical branches of the network nearly transversely, but others appear considerably elongated, because through these the knife has passed obliquely or even in the direction of their length. These are the branches that cross over obliquely or horizontally and connect the ducts into a network.

If now one of the longitudinal sections be examined, a much better idea of this network of vessels will be obtained. The parenchyma-cells in this view are considerably elongated, and if the section run through one of the clusters of milk-ducts it will be seen that the tangled network of vessels has its irregular meshes mostly much elongated in a direction lengthwise of the stem.

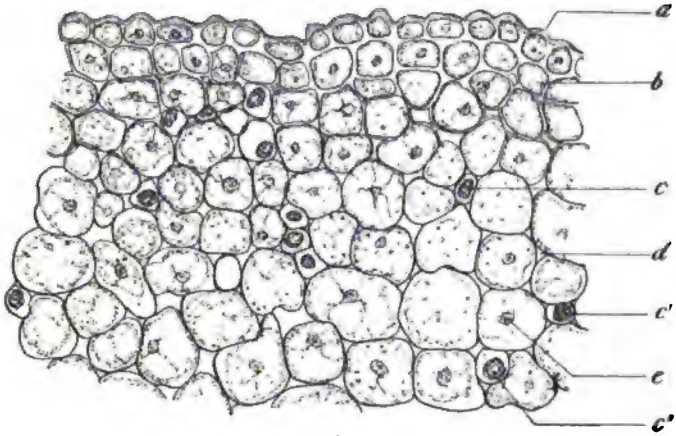
If the appropriate tests be applied, it will be found that the walls of the milk-vessels are of cellulose, that the latex, like the rest of the root, is destitute of starch, and that it contains resinous matters in considerable abundance.

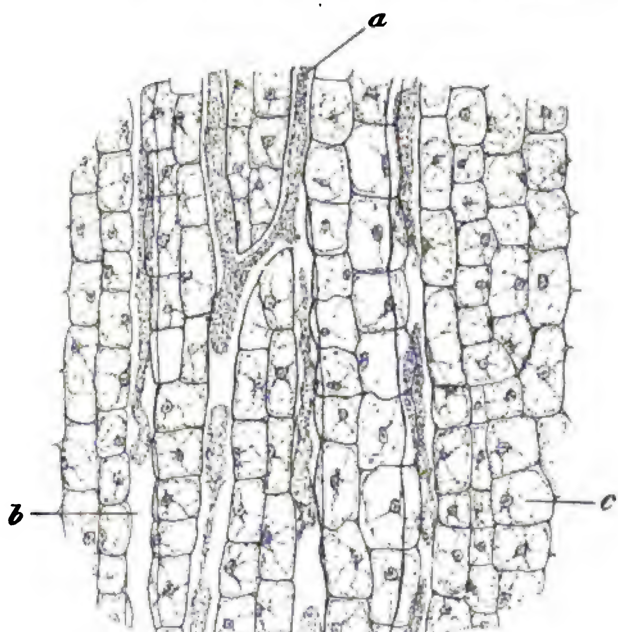
To sum up the observations made, the chief difference between simple and complex laticiferous tissue is that the latter exists as a complicated network, while the former consists mostly of independent tubes. This difference corresponds to a difference of origin. A simple milk-tube begins as an ordinary meristem-cell, and grows as the plant grows, forming a long, unbranching, or sparingly branching tube; it is at maturity still a single cell. Complex laticiferous tissue, on the other hand, is produced by the coalescence of a large number of cells to form a network of anastomosing tubes. There appears to be a close relationship between isolated secretion-cells and this form of milk-tissue. In the Poppy family, for example, one finds in some species only the isolated secretion-cells; in some others, as in the Bloodroot, both isolated secretion-cells and those that are arranged in chains approximating a milk-duct in appearance and structure; and in the Poppy and Celandine the fully-developed network of milk-ducts.

The fluid of milk-tissues appears to be partly nutritive, since

it contains albumins and carbohydrates; but it is partly, perhaps chiefly, waste or excretory, for the resinous and some of the mineral matters can have no nutritive value to the plant. The excretory matters, however, may still serve the purpose of protection.

The latex is not always of the same color, but differs considerably in different plants: it is often white or yellow, sometimes orange or even deep orange-red, as in Bloodroot, but it is sometimes nearly colorless, as in the Oleander.





2

PLATE LVII., FIG. 1.—Transverse Section of outer part of young Stem of Asclepias cornuti: *a*, epidermal cell; *b*, cell of imperfectly-formed collenchyma; *c*, *c′*, *c″*, latex-tubes; *d*, an intercellular space in parenchyma; *e*, nucleus of parenchyma-cell. (Magnification, 210 diameters.)

FIG. 2.—Longitudinal Section of the same Stem through the Mesophlœum: *a*, a milk-tube which sends an anastomosing branch to an adjacent tube; *b*, another tube from which much of the latex has escaped; *c*, one of the parenchyma-cells among which the milk-tubes are dispersed. (Magnification, 210 diameters.)

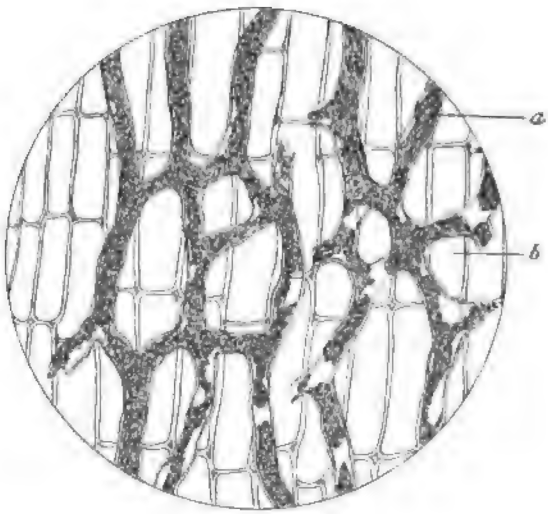


PLATE LVIII.—A small portion of the Cortical Parenchyma of the Dandelion root in longitudinal section, showing complex milk-tissue: *a*, one of the branches of the network of milk-vessels; *b*, one of the parenchyma-cells. (Magnification about 170 diameters.)

EXERCISE XV.

STUDY OF STARCHES.

Most of the cereals, such as wheat, rye, oats, barley, and maize, and many root- and rhizome-drugs, such as sarsaparilla, calumba, belladonna, bryony, colchicum, and aconite, afford starches interesting to study, and many of these starches show very marked characteristics.

I.—For the first part of this study attention will be given to the Potato tuber, which, as has already been learned, is rich in starchy contents.

Selecting a potato that is ripe or nearly so, a number of sections are made perpendicular to the corky exterior, and a few others parallel to it. Let one of the former be mounted in a drop of water, and be examined first with the low and then with a higher power.

At the exterior is found a layer of cork composed of from fifteen to twenty tiers of tabular cells. The outside layers of this cork are composed of shrivelled, opaque cells which are more or less disrupted and peeling off at the surface. There is no proper collenchyma, but immediately interior to the phellogen-layer are parenchyma-cells smaller in size and more compactly arranged than those farther interior. They are also richer in proteids and much less rich in starch. Few of the cells are quite destitute of the latter, but the granules are small. A rather large nucleus and granular protoplasm are plainly discernible, as well as cubical crystals and rounded proteid bodies of considerable size.

In the parenchyma farther interior the cubical crystals are wanting, and the nucleus, though present in most of the cells, is often difficult to identify by reason of the abundance of starch-grains surrounding it.

Let now a drop of potassium-iodide iodine be placed at the edge of the cover-glass and be allowed to run under by capil-

lary attraction. Watching the effects through the microscope, it is seen that as the reagent comes into contact with the starch-grains they become blue; the color rapidly deepens until the grains can no longer transmit light, and they therefore appear black. The nucleus, protoplasm, and crystals stain brown. The fact that the latter behave with the reagent in a manner similar to protoplasm leads to the inference that they are not inorganic in their nature, as might at first be supposed, but are of a proteid character, as will be proved later on.

It will be observed that the small starch-grains in the exterior parenchyma-cells are not usually isolated, but occur in groups about granular masses of protoplasm, and are often clustered about the nucleus. The starch-formers or *amyloplasts*—proteid particles whose function it is to build up the starch-grain—occur, in fact, in clusters, and if they could be rendered visible one would be found attached to each young starch-grain; but in order to render them visible a special method of staining must be adopted. This will be done presently; but let the structure of the starch-grain itself first be studied.

For this purpose let scrapings with a knife-blade from the freshly-cut surface of a potato be made, and let a small quantity of these scrapings be placed on a slide in a drop of water, covered, and examined. By focusing on some of the larger grains it will be seen that they are mostly ovate in outline, and toward the smaller end is noticeable a rounded spot occasionally fissured by a straight or angular fissure, but more commonly without one. This fissured or unfissured spot is the *hilum* or nucleus, which marks the point where the growth of the grain began. About the hilum may be discerned a series of curves, at first concentric, but farther away becoming more and more eccentric. They are stratification-lines, and their arrangement leads to the conjecture that the growth was at first nearly equal, afterward much greater on one side. This conjecture is confirmed by a comparison of young grains with old or mature ones: in the former the hilum is nearly central, and if any stratification-lines are discernible at all, they are concentric or nearly so; in the mature grain the hilum is much to one side of the centre and many of the curves are eccentric.

If the point of a needle be gently laid on the surface of the

cover while the handle is held in the hand, and at the same time the starch-grains be viewed through the microscope, the agitation due to the trembling of the hand will cause some of the grains to turn over or turn up on edge, and it may then be seen that they are thickest at the hilum end, becoming much thinner at the opposite or broad end.

Attaching now the polariscope to the microscope, and viewing the grains between the crossed Nicol prisms with a moderate magnifying power, it will be found that the grains polarize beautifully, and a dark, very unequal-armed cross is seen in each grain, the arms of the cross intersecting at the nucleus. This effect is not due to crystalline structure, for there is no evidence of such a structure in starch-grains: it is caused by tension or strain among the layers composing the grains.

Let an effort now be made to determine the cause of the stratified appearance of the grain. Placing a drop of 5 per cent. aqueous solution of potassium hydrate at the edge of the cover-glass and letting it slowly run under, it will be observed that as soon as the alkali comes into contact with the grain the latter begins to swell, and for an instant the stratification-lines become more distinct; but as the swelling continues they grow indistinct and disappear, and finally the grain itself dissolves.

These effects may best be accounted for by supposing that the different layers contain normally different proportions of water, and that the more watery layers at first absorb water under the influence of the alkali more rapidly than do the less watery layers, and in this way the lines are brought out more distinctly; but soon the other layers begin to take up water also, and the lines therefore, as the distribution of water becomes equalized, disappear.

Let now a test be applied to ascertain whether this theory is correct. If it is correct, the grains should, on thorough drying, lose their stratified appearance. A quantity of starch is therefore heated on some slides for a time at a temperature sufficiently high to evaporate the water, but too low to destroy the structure of the grain—say, a temperature of 60° Centigrade. If then the grains be mounted in some liquid that contains no water and yet is not too refractive to permit of seeing the grains distinctly—as a solution of dammar in equal parts of oil of turpentine and

benzol, for example—the lines will be found to have disappeared. But the proof may be strengthened by means of the following experiment: Taking some of the thoroughly dried grains, they are treated on the slide with a 5 per cent. solution of silver nitrate in distilled water, the liquid being allowed to remain in contact with the starch for an hour or more; draining away the reagent and drying the grains, they are treated for an hour or more with 5 per cent. solution of common salt, and then, after rinsing in clean water, they are exposed for an hour or more to the bright sunshine. If it be a fact that some of the layers are capable of taking up more water than others, the silver chloride will have been precipitated more abundantly in these layers, and when the chloride has been reduced by the action of sunlight the stratification of the grains should appear very distinct. The experiment, if properly tried, fully justifies expectations and bears out the theory.

Studying the structure of the grains still further, it is found that some are double, containing two nuclei, each with the concentric and eccentric markings about it, and a dividing-line distinctly recognizable between the two portions of the grain; sometimes even triple grains are found. In other instances the grains are not properly double or triple, but are binucleated or trinucleated. Each nucleus has a few concentric curves about it, but exterior to these are curves which belong to the entire grain and enclose all the nuclei. In many starches—as, for example, those of the sarsaparillas and of the oat—compound and multinucleated grains are the rule, and not the exception. There are great differences also among the starches of different plants, not only in the size and shape of the grains, but in the position of the hilum (whether central or eccentric), in the number and distinctness of the stratification-lines, in the degree to which the hilum is fissured, and in the character of the fissures.

Let now an endeavor be made to render visible the amyloplasts. To do this let some of each of the kinds of sections prepared be placed in a saturated aqueous solution of bichloride of mercury, and be allowed to remain there for twelve hours to fix the proteids. Afterward they should be washed thoroughly in dilute alcohol to remove the bichloride. The sections are then placed in a dilute solution of acid fuchsin for half an hour, rinsed well

in water to remove the color from the cell-walls, anhydrated, treated very briefly with oil of cloves, and mounted in xylol balsam.

Placing one of the preparations under the microscope and focusing upon some of the parenchyma-cells but little interior to the cork, it will be found that the cubical crystals already referred to have been stained a deep-red color, that granular particles in the nucleus have also stained the same color, that other rounded or but slightly angular bodies have stained in the same way, and that attached to the ends or sides of some of the smaller or medium-sized starch-grains are similarly stained bodies. The latter are the amyloplasts. These bodies are in their nature similar to chlorophyll bodies, but without the chlorophyll, and there are the best of reasons for believing that most starch-grains are formed by the agency of either the one or the other. In a few instances, however, they are believed to be formed by the agency of ordinary protoplasm.

It is more than ever evident that the cubical crystals are proteid bodies, for they have stained like them. They are, in fact, good examples of protein crystals or crystalloids. In the potato they are mostly cubical, but some may be found with the corners and angles rounded off so that they are nearly spherical.

If a fresh section be taken, and, having focused the microscope on one of the crystalloids, a drop of potassium-hydrate solution be allowed to run under the cover-glass, the crystalloid will be observed to swell, to lose its sharp angles, and finally to disappear. This behavior is that of a proteid, but not that of an inorganic crystal.

II.—Let attention now be directed to a different starch, that of Colchicum autumnale. It will be sufficient to scrape upon a slide a little of the tissue from the cut surface of one of the dried sections of the corm commonly sold at apothecary shops, and to mount the scrapings in a drop of water. Starch-grains will be seen in great abundance, but ones very different from those observed in the potato. They are not only much smaller and different in shape, but the hilum is central or nearly so, and very strongly and distinctly fissured even in the more minute grains. The fissures are usually stellate, but sometimes consist of a single straight or curved slit. Moreover, the majority of

the grains are seen either in clusters of two, three, or more, or else the squared ends or sides show that the grains have been a part of such clusters. There is, however, a goodly sprinkling of grains that are strictly simple, and these are all spherical or nearly so.

Stratification-curves are in this species difficult to detect without resort to the silver-nitrate process, by which, however, a few strata may be seen, though they are not nearly so numerous as in the starch of the potato.

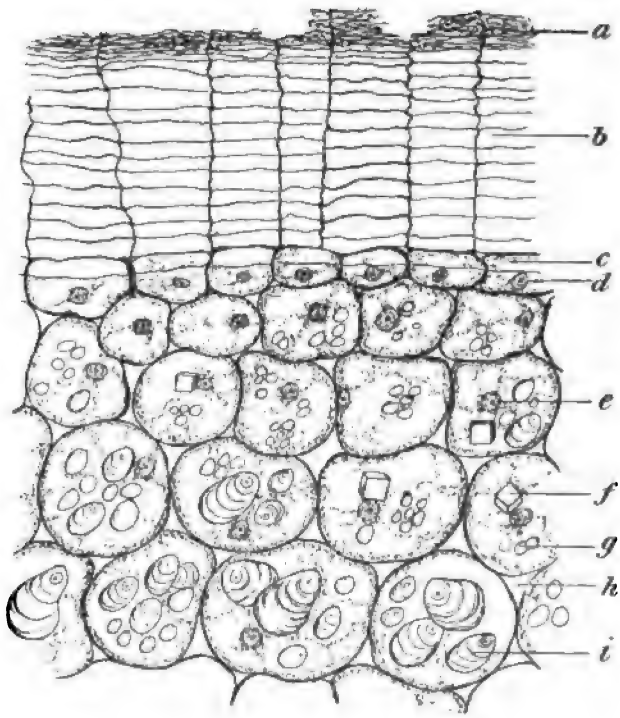
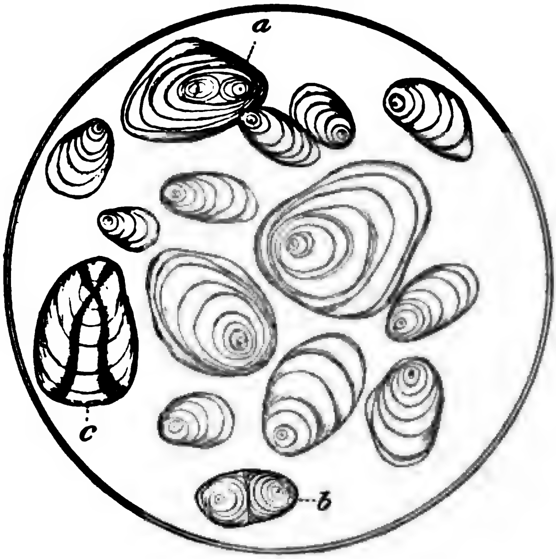


PLATE LIX.—A small portion of a Cross-section of the Potato Tuber, showing the cork and a little of the sublying parenchyma: *a*, old cork; *b*, younger but mature cork; *c*, youngest cork-cells; *d*, phellogen layer; *e*, nucleus of one of the parenchyma-cells, which also contains a cubical crystalloid; *f*, crystalloid; *g*, small starch-grains; *h*, intercellular space; *i*, larger starch-grain, showing hilum and stratification-curves. (Magnification, 120 diameters.)



1

2

PLATE LX., FIG. 1.—Starch from Potato (magnified 305 diameters): *a*, a bi-nucleated grain; *b*, a double grain; *c*, a grain as seen under the polariscope.

FIG. 2.—Starch from the Corm of Colchicum autumnale (magnified 310 diameters).

EXERCISE XVI.

STUDY OF ALEURONE-GRAINS.

THE seeds of the following plants afford interesting material: Croton Tiglium, *L.*, Ricinus communis, *L.*, Bertholletia excelsa, *Humboldt* and *Bonpland*, Pisum sativum, *L.*, Delphinium Staphisagria, *L.*, Lupinus varius, *L.*, and Triticum vulgare, *Villars.*

Most plants lay up some portion of their reserve food material in the form of albuminous matters of various kinds, as well as in the form of starch, oil, inulin, and sugar. One of the most important of the albuminous reserve food materials is aleurone, found chiefly in seeds, and most abundantly in oily ones. It usually occurs in the form of rounded granules which are often quite small, but which sometimes attain a considerable size, as in the Croton and Castor Beans and in the Brazil-nut. In many cases the granules appear to be homogeneous in structure or nearly so, but in other cases they contain various substances differing more or less in constitution from the main body of the grain. These substances may be oily matters, mineral crystals, and crystalloids.

For this study is selected the endosperm of the Castor Bean. On removing the seed-coats the endosperm will be found in good condition for sectioning without further preparation.

A number of thin sections should be cut and be set aside, but not in liquid, until required for use as directed.

A section is first mounted in a drop of strong glycerin, and after finding the thinnest part of the section with the low power it is focused upon with the higher one. The aleurone-grains are seen as rather large, nearly spherical or ellipsoidal bodies occupying the larger portion of the interior of the cells. In appearance they are not unlike starch-grains, but appropriate tests easily prove their proteid nature, and prove also that this seed does not contain starch. The aleurone is intermixed with finely granular and rather opaque matters consisting of a mixture of fats and amorphous proteids.

At first the aleurone-grains appear homogeneous, but presently the clearing action of the glycerin comes into play, and through the now more transparent exterior portion of the grain is seen a denser, many sided body, the crystalloid, which is often so large that the rest of the grain forms scarcely more than a pellicle about it. At other times, however, the crystalloid is relatively much smaller, or the grain may even contain two or more crystalloids. There are also usually seen on the interior of the grain, alongside of the crystalloid, one or more small, globular, strongly refractive bodies called *globoids*. They are not organic in their nature, being composed of the double phosphate of calcium and magnesium.

If now the cover-glass be removed, and, after adding a drop of the strong potassium-iodide iodine and allowing it a few minutes to penetrate the structure, it be replaced and the section again be examined, the grains will be found to have acquired a brown color, especially deep in the crystalloids. The reaction indicates their proteid character. The globoids remain unstained.

If there be applied to a section a drop of 1 or 2 per cent. solution of potassium hydrate, the crystalloids will swell rapidly, lose their angles, and disappear as did those observed in the potato.

If now a fresh section be placed upon the slide, covered, and a drop of water be allowed to run under the cover-glass, the oil will be observed to run together and to form drops, probably from the solution of the albuminous pellicles which keep the minute droplets apart; the oil flows out of the ruptured tissues, and may soon be observed in drops at the borders of the section as well as in some of the cells. As the water comes into contact with the aleurone-grains their ground-substance swells and rather rapidly disappears from view, leaving the crystalloids for a few moments standing out sharp and clear; but soon these too begin to swell and to lose their angles, though it takes them a long time to disappear wholly.

If, while the crystalloids are still sharply defined, there be allowed to run under the cover-glass some absolute alcohol, the structure of the grains may still better be seen, the ground-substance being still visible but transparent, and the crystalloids and globoids being sharply defined on the interior. Still more pleas-

ing results, however, may be obtained by one of the following processes:

(1) Place a few of the sections, cut as thin as possible, in a 5 per cent. alcoholic solution of bichloride of mercury to fix them, permitting them to remain in the solution for several hours; then remove the sections from the fixing solution, and, having washed them thoroughly in alcohol to get rid of the bichloride, place them for fifteen or twenty minutes in a rather dilute solution of acid fuchsin; then rinse them well in water or dilute alcohol to remove the bulk of the stain from the cell-walls, anhydrate them, pass them rather rapidly through oil of cloves, and mount them in xylol balsam. In this way the crystalloids will be stained a deep-red color, while but slight traces of color will remain in the ground-substance and in the cell-walls, so that the crystalloids appear very sharply defined.

(2) The second method is quite as satisfactory and is much more rapid. The sections are first treated for about twenty minutes or half an hour with a dilute aqueous solution of tannin, are rapidly rinsed in pure water, and are transferred to a 1 or 2 per cent. solution of osmic acid in distilled water. They are allowed to remain in this solution only a few moments, when they are thoroughly washed in pure water to get rid of the last traces of the acid. This is necessary, because if not done the section will ultimately become so opaque that the structure cannot be recognized. The crystalloids now appear stained a deep-brown color, while the ground-substance is only very slightly stained. If desired, the sections may be mounted permanently in glycerin gelatin or be anhydrated by means of absolute alcohol and mounted in balsam.

Since the sections contain fixed oil, a few minutes may profitably be spent in learning to apply the tests for its recognition. Had what took place when one of the sections was treated with absolute alcohol been observed closely, it would have been seen that the oil-globules gradually disappeared from view. This is because castor oil is one of the very few fixed oils which are freely soluble in alcohol.

Now let a fresh section be treated with a few drops of the alcannin solution, and it will be found after a few minutes that the oil-globules that have flowed out around the margins of the section, as well as those that have formed in the cells, and even

the fine granules in the cell, not otherwise optically distinguishable as oil-drops, have stained a deep-red color. In this behavior fats agree with volatile oils and resins, but differ from all other substances.

Lastly, let another section be mounted dry, the cover-glass being pressed down rather strongly, so as to force some of the oil out of the cells to the edge of the section. If now a drop of the cyanin solution be allowed to run under the cover-glass, the refractive globules of oil will soon be stained a brilliant blue.

Fixed oils, like aleurone-grains and starch, serve the plant as reserve food materials. They occur in a very large proportion of seeds and spores, and sometimes constitute the greater part of their weight.

Crystalloids also most often occur in seeds, but sometimes elsewhere in the plant. They occur in the epidermis of the Ivy, in the young shoots of the Canna, in the vegetative parts of many marine algæ, in the mycelium of a few fungi, and in minute form they have been observed in the nuclei of the cells of various plants.

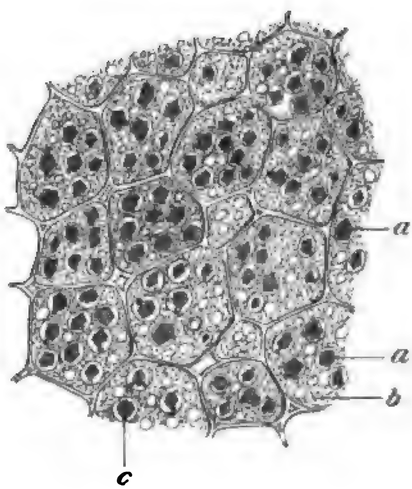


PLATE LXI.—A few Cells from the Endosperm of Ricinus communis, showing aleurone-grains, their contained crystalloids and globoids, and the granular ground substance of the cells, containing proteids and oil (magnification, 330 diameters). Drawing made from a section which had been treated by the tannin-osmic-acid process. *a*, *a*, crystalloids in aleurone-grains; *b*, granular ground substance of cell; *c*, a globoid.

EXERCISE XVII.

STUDY OF CHLOROPLASTS AND COLORING MATTERS.

CHLOROPLASTS or chlorophyll bodies occur in nearly all green plants; but, since in many of the higher species these bodies are quite small and often very much crowded in the cells, selections for study would better be made from some of the following plants: any of the larger-leaved mosses or liverworts; the upper part of the thallus of the Common Marchantia (Marchantia polymorpha, *L.*); the prothallia of almost any species of fern; the leaves of some aquatic phanerogams, as those of the Tape- or Eel-grass (Vallisneria spiralis, *L.*), of the Water-weed (Elodea Canadensis, *Michx.*), and of the more transparent-leaved species of Pondweed (Potamogeton); many of the fresh-water algæ, as the members of the genus Spirogyra, where the chloroplasts form spiral bands in the cells, and the members of the genus Zygnema, where they have a stellate form, will also afford interesting comparative studies. Suitable mosses, Marchantia, and fern prothallia may be found growing on the flower-pots and damp walls of greenhouses at any season of the year.

In the great majority of cases chloroplasts are rounded or ellipsoidal bodies; they very rarely take such shapes as those of Spirogyra or Zygnema. They are proteids, perhaps to be regarded as a part of the living protoplasm of the cell, since they have the power of growth and division. Wherever they occur they are intimately associated with ordinary protoplasm, being imbedded in the more granular portions of it and being carried about by its movements. These movements are influenced by the light which falls upon the cells, so that the positions occupied by the chloroplasts in darkness or when the light is weak are different from those occupied by them when the light is intense.

I.—Let chloroplasts as found in a moss leaf first be studied.

Placing the leaf of a moss, plucked fresh from the living plant, on a slide, and mounting it in a drop of water, there will

be seen great numbers of distinctly outlined green bodies among the otherwise colorless cell-contents. These green bodies are the chloroplasts, the bodies which communicate the color to all the green parts of a plant. Viewing them with the high power, they are seen to be for the most part spherical or nearly so; but some are rather elongated or oblong in outline, and occasionally one may be seen that is elongated and strongly contracted midway between its two ends. The latter two forms represent successive stages in the process of division, the form with a constriction in its middle being nearly ready to separate into two.

If now a few drops of alcohol be permitted to run under the cover-glass and the effects be observed, it will be seen that the green color gradually fades out of the chloroplasts without otherwise changing their form or appearance; as this change takes place the cell-sap acquires a clear-green color. The chlorophyll—that is, the green coloring matter—has dissolved in the alcohol. The chloroplast and the chlorophyll which it contains are therefore distinct things.

An instructive experiment is to crush a few green leaves—such as those of the Hyacinth, for example—to treat them with strong alcohol, and, after the mixture has macerated for half an hour, to filter off the alcoholic solution. Much of the chlorophyll will have passed into solution in the alcohol, and the liquid will have acquired a color which by transmitted light is a vivid green, but by reflected light is a deep red.

Returning now to the leaf of the moss, one that has had the chlorophyll removed from it by the action of alcohol is mounted in a drop of potassium-iodide iodine. The ordinary protoplasm and cell-nucleus, previously so transparent as to be invisible, are now distinctly seen by reason of the brownish color they have acquired, and chloroplasts also show their proteid nature by having acquired a deep-brown color.

One of the chief functions of chloroplasts is to form starch; this is accomplished through the agency of the light acting upon the contained chlorophyll. The starch thus formed is for the time being laid up in the form of minute corpuscles in the interior of the chloroplasts. Ordinarily, however, these starch-corpuscles are invisible, but they may be brought to view by means of appropriate tests. The following process may be

adopted to demonstrate their presence: Placing a drop of potassium-hydrate solution at the edge of the cover-glass of the iodine-stained specimen just examined, and letting it run under, the section is watched through the microscope to observe what takes place. As the alkaline liquid comes into contact with the chloroplasts they swell and become transparent, momentarily revealing the blue-stained starch-grains; but these very soon lose their color, swell, and presently disappear from view.

A better method, therefore, is the following: Apply to a leaf that has been bleached by alcohol a drop or two of chloral-hydrate iodine. This would better be done by mounting the leaf in a drop of water, and then, after focusing the microscope, placing a drop of the reagent at the edge of the cover, because it is important to observe the beginnings of the reaction. When the reagent comes into contact with the chloroplasts they swell rapidly and become transparent, revealing the starch-granules, which swell much more slowly and are stained blue by the iodine. Presently the chloroplast completely disappears from view, leaving the starch-granules standing out sharp and clear. They will be seen to be mostly oblong, rod-like, or crescent-shaped bodies, some of them being exceedingly minute. There are usually several granules in each chloroplast.

In a study of this kind it is important that the leaves be taken from vigorously growing plants that have been exposed to sunlight some hours immediately before fixation and bleaching in alcohol, otherwise the chloroplasts may contain little or no starch, for at night or in darkness the starch that accumulates in the chloroplasts during the daylight is dissolved and transferred to other parts of the plant.

II.—The colors of flowers are due to various causes: sometimes to proteid corpuscles similar in their nature to chloroplasts, but containing some other coloring matter different from chlorophyll; sometimes to a coloring principle in solution in the cell-sap; and sometimes to crystalline coloring matters in the cells. Most of the shades of yellow and orange, and in rare instances some of the blues, are due to color-corpuscles, but these are seldom so definite in form or so well defined as are chlorophyll-corpuscles. Not infrequently, however, these color-corpuscles are produced by changes in the chloroplasts, and the colors they con-

tain are the product, in some instances at least, of chemical changes in the chlorophyll. This is the fact, probably, with many of the colors of autumn leaves.

Anthoxanthin is the coloring principle which is perhaps the commonest in the color-corpuscles of yellow flowers.

Most of the shades of violet, blue, and red, as well as now and then a yellow, are due to coloring matters in solution and diffused through the cell-sap. Erythrophyll is the commonest of the red coloring matters belonging to this category, and anthocyanin is the commonest of the blues.

Flowers of any of the following plants may be studied with profit: the Nasturtium (Tropeolum majus, *L.*), the Allamanda (Allamanda Schottii, *Pohl*), the Spiderwort (Tradescantia Virginica, *L*), the Toad-flax (Linaria vulgaris, *Mill.*), the red-flowered form of the Shrubby Mallow (Hibiscus Syriacus, *L.*), and the Red Rose (Rosa Gallica, *L.*).

From this list is selected for special study the flower of Linaria vulgaris, a plant now common throughout the Eastern United States, and known under the popular names of "Snapdragon," "Butter-and-Eggs," and "Toad-flax." The corolla is gamopetalous, bilabiate, and strongly calcarate. The prevailing color is lemon-yellow, but the palate is orange-colored. The latter is also provided with numerous striated hairs. The most favorable portions for study are not the most deeply colored ones, for the hairs and the conical elevations on the epidermal cells interfere with the view of the cell-contents.

A specimen is therefore prepared as follows: Seizing one of the lips with each hand, the lower lip is sharply bent back and the flower is torn down through the spur to the apex of the latter. The epidermis will in most cases strip off from the spur by this method, and after cutting away the other portions with scissors it may be mounted in a drop of water and be examined.

The cells will be found to contain a light-yellow coloring matter dissolved in the cell-sap. Besides this there may with some difficulty be made out the cell-nucleus and the nearly transparent protoplasm. There are also present some small, rounded, dense, and colorless particles which the iodine test would prove to be starch-grains.

But the diffused yellow coloring matter is not the only one

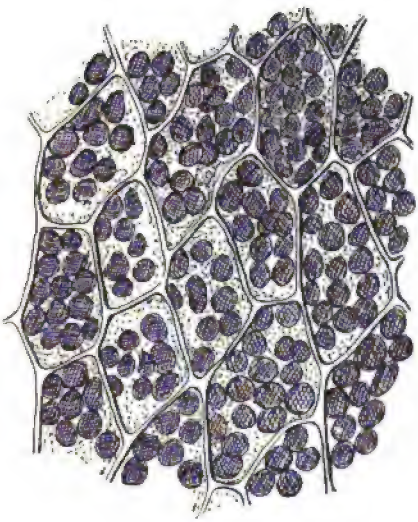
present in this case. In some parts of the epidermis, though not in all, will be found numerous small crystals of a distinctly yellow color and of very various shapes: some are prismatic and square-ended, others are prismatic and have the ends terminated by pyramids, others are in the form of two pyramids placed base to base; many are elongated into acicular forms, some are tabular, and still others form globular or stellate masses, each mass showing a distinctly radial structure. Viewed by polarized light, the crystals give splendid polarization effects, but with reagents their behavior is quite different from that of the ordinary mineral crystals found in plants. If treated with potassium-hydrate solution, they quickly dissolve and disappear, at the same time communicating to the tissue a red or orange-red color. The effect of the solution is most striking if the crystals be viewed by polarized light while the potassium hydrate is permitted to run under the cover-glass.

The crystals are also dissolved, only a little more slowly, by means of the chloral-hydrate iodine solution. This reagent also establishes the fact that fine starch-grains exist in the cells, and most abundantly in those which contain fewest of the crystals.

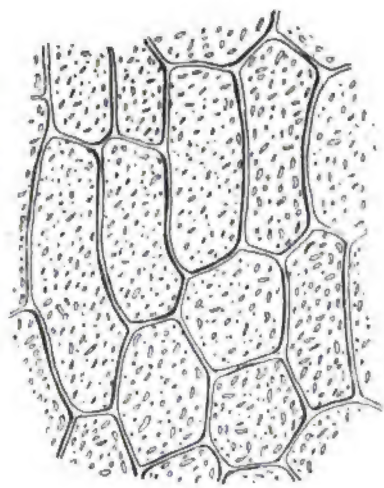
The crystals are insoluble in acetic acid, but dissolve slowly in hydrochloric acid, more rapidly in sulphuric acid, and in both instances with the production of a red color. In alcohol they are insoluble.

In the bright-yellow corolla of Allamanda the color resides in small, mostly rounded corpuscles which do not polarize light, which are insoluble in potassium-hydrate solution and in alcohol, which are quickly stained a deep-red color by alcannin solution, and which are also stained a deep blue, though more slowly, by cyanin solution.

If the epidermis be stripped off from the lower, deep-red portion of the petal of Hibiscus, and be mounted in water, the cells will appear to be filled with a bright-red sap in which the cell-nucleus is visible as a lighter spot. No granular coloring matter exists in these cells.



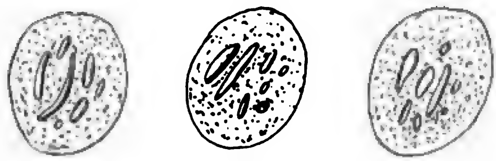
1



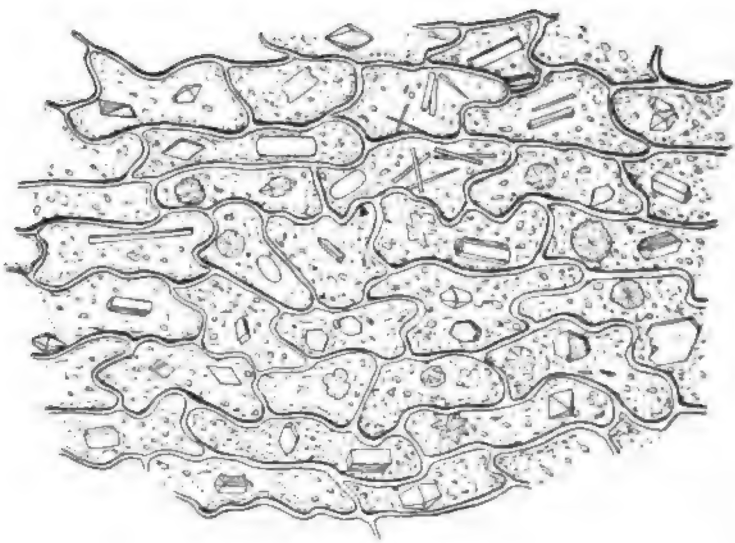
2

PLATE LXII., FIG. 1.—A few Cells from the Leaf of a Moss, showing numerous chloroplasts and finely granular protoplasm in the cells (magnified 535 diameters).

FIG. 2.—A few Cells from the same Leaf after treatment with chloral-hydrate iodine, which has destroyed the chloroplasts, leaving the small starch-grains which they contained undissolved, but somewhat swollen (magnified 535 diameters).



1



2

PLATE LXIII., FIG. 1.—Three of the Chloroplasts from the Leaf of a Moss, somewhat swollen and rendered transparent by the chloral, but not yet dissolved, showing the starch-granules in their interior (magnification, 800 diameters).

FIG. 2.—Portion of Epidermis of the Corolla-spur of Linaria vulgaris, showing color-crystals (magnification, 535 diameters).

EXERCISE XVIII.

STUDY OF INULIN AND SUGAR.

I.—THE roots of any of the following plants, if collected in autumn, contain inulin in abundance, and afford convenient objects for the study of this carbohydrate: the Dandelion (Taraxacum officinale, *Weber*), the Chicory (Cichorium Intybus, *L.*), the Salsify (Tragopogon porrifolius, *L.*), the Burdock (Arctium Lappa, *L.*), the Pellitory (Anacyclus Pyrethrum, *DC.*), the Sow-thistle (Sonchus oleraceus, *L.*), and the Elecampane (Inula Helenium, *L.*).

Inulin, though resembling starch in its chemical nature, and serving the same purpose in the plant, does not naturally occur in the form of solid particles, but in solution in the cell-sap. It may, however, be obtained in the crystalline form by taking advantage of its insolubility in strong alcohol.

The roots of Chicory are selected for this study. They should, immediately after removal from the soil and washing, be cut into pieces a centimetre or a centimetre and a half long, be placed in strong alcohol, and be allowed to remain there for some time—at least several days. The inulin gradually crystallizes out, and may then be seen in the cells and intercellular spaces of the plant.

Sections, either transverse or longitudinal, of the root may be made and be mounted either in strong alcohol or in strong glycerin for study. The crystals dissolve too rapidly if mounted in aqueous fluids. They may be seen under the low power as spherical, spheroidal, or nodular masses in the cells, and particularly in the radial, fissure-like, intercellular spaces in the bark. They are transparent and refractive, and they show a central dark spot or radial fissure and several concentric circles as well as numerous fine radial lines. The masses are not always spherical: sometimes they are hemispherical and formed against one side of the cell-

wall, and sometimes there may even be found a sphere-crystal which is bisected by the cell-wall, one-half of the crystal lying on one side of the wall, the other half on the other side. Sometimes several of the crystalline spheres starting from neighboring centres will be seen to have coalesced to form a nodular mass, each part, however, preserving its concentric and radial structure.

The markings and the structure of these sphere-crystals are better seen if a section be treated for a few minutes with strong alcoholic solution of iodine, which penetrates between the fine crystals composing the mass, staining it yellowish. The effects of the stain will show more distinctly if the section, after removal from the iodine, be dipped for a moment in alcohol to wash away the excess of iodine; but this immersion must not be of too long duration, or the whole structure will be decolorized.

If to a section mounted in strong alcohol or in strong glycerin is added a little water by allowing it to run under the cover-glass, it will be found after a short time that solution has begun to take place, and the radial structure may then be seen more distinctly. The masses, in fact, are made up of delicate, needle-like crystals radiating from a common centre.

To another section of the same material let there be added a single drop of 10 per cent. solution of thymol in strong alcohol, then, after a few minutes, a single drop of strong sulphuric acid, the object then be covered, and the slide be warmed over a lamp-flame: the crystals will have dissolved and disappeared, but a red color will have been produced in the section, showing the presence of a carbohydrate. The reaction is not, however, distinctive of inulin, since any other soluble carbohydrate behaves in the same way. But the test often enables one to distinguish between sphere-crystals of inulin and similar ones of other substances—for example, those of calcium phosphate, which may be associated with inulin in the cells.

II.—Let attention now be given to another carbohydrate—namely, sugar, or, rather, to the sugars, for there are several of them. Objects favorable for the study of these substances are the following: the stems and young fruits of Maize (Zea Mays, *L.*); the stems of Sorghum (Holchus saccharatus, *L.*); the stems of Sugar-cane (Saccharum officinarum, *L.*); the root of the Sugar-

beet (Beta vulgaris, *L.*); the root of the Sweet Potato (Convolvulus batatas, *L.*); the root of the Carrot (Daucus Carota, *L.*); the fruit of the Pear (Pyrus communis, *L.*); the fruit of the Apple (Pyrus Malus, *L.*); the fruit of the Musk-melon (Cucumis Melo, *L.*); the fruit of the Banana (Musa sapientum, *L.*); and the fruit of the Peach (Amygdalus persica, *L.*).

Let a peach be selected for the first experiment. A fruit which is fully ripe, but not yet soft, should be chosen, and the sections need not be very thin. One of them is placed on a slide and treated first with the 10 per cent. solution of thymol and then with a drop of strong sulphuric acid, as was done in the study of inulin. The result is the same except that the red color appears more rapidly and without the application of heat. The experiment may be varied by applying to a fresh section a drop or two of 20 per cent. alcoholic solution of α-naphthol, and afterward a drop of strong sulphuric acid, when a deep-violet color will rapidly appear in and around the section.

Sections of any of the other objects mentioned in the above list will yield similar results; but, since sugar is more abundant in some than in others, the color-reactions will differ considerably in intensity.

These reagents, however, do not enable one to distinguish between the different kinds of sugars, nor even to tell sugar from some other carbohydrates, without a good deal of difficulty; therefore it is advisable to try another test.

One of the best reagents for the purpose is Fehling's solution (see Introduction). Ten cubic centimetres of the solution are heated to boiling in an evaporating-dish, and while the solution is still at the boiling temperature a section is immersed in it for about two seconds and then withdrawn. If a sugar belonging to the glucose group be present, the section will be colored by an ochrey-red deposit of copper suboxide in the tissues. If no deposit has taken place at the end of two seconds, but a red one does occur after boiling for a longer time, it may be concluded that a saccharose instead of a glucose is present. The reason why, in the latter case, the suboxide deposit does not occur at once is because saccharose, as such, is not capable of reducing the copper from its solution, but boiling soon changes saccharose into invert-sugar, which is capable of producing the change.

If even after long boiling no red deposit takes place, inulin, mannite, or starch may be present, but neither glucose nor saccharose sugars.

The common Carrot contains cane-sugar, and a section of this may now be tested, so as to observe the difference in the reaction between the two sugar groups.

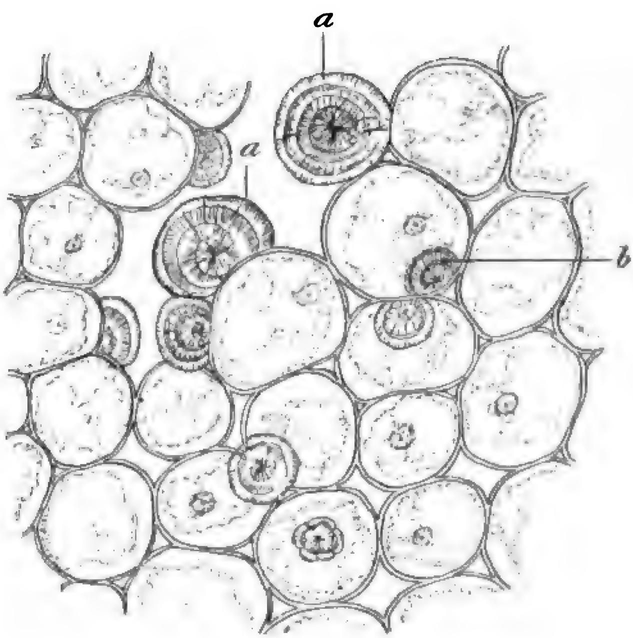


PLATE LXIV.—Cross-section of a small portion of the Parenchymatous Tissues from the inner layer of the bark of the root of Chicory (magnified 330 diameters). The root had been soaked for some time in strong alcohol before sectioning. *a*, *a*, sphere-crystals of inulin in an intercellular space; *b*, a smaller crystal, partially disintegrated, in a cell.

EXERCISE XIX.

STUDY OF SECRETION-SACS.

SECRETION-SACS are cells which at maturity have lost their protoplasm, and therefore their proper cellular character, and become filled with secreted matters. Their forms differ in different plants, but more commonly they resemble parenchyma-cells in appearance and in the character of their walls. Sometimes, however, they are much elongated and might be mistaken for laticiferous tissue, and sometimes their walls are thickened and more or less lignified. They are usually classified, according to the nature of their contents, into resin-sacs, mucilage-sacs, crystal-sacs, tannin-sacs, etc. Many are mixed in their character, containing both mucilage and crystals or both resins and mucilage; or along with resinous contents there may be tannic or alkaloidal principles.

The following objects afford good examples of the principal groups:

(1) *Resin-sacs:* the rhizome of Ginger (Zingiber officinale, *Roscoe*); the rhizome of Sweet Flag (Acorus Calamus, *L.*); the bark of the Sweet Bay (Magnolia glauca, *L.*); the rhizome of Bloodroot (Sanguinaria Canadensis, *L.*); and the stem of the Lizard's Tail (Saururus cernuus, *L.*).

(2) *Mucilage-sacs:* the root of the Marshmallow (Althæa officinalis, *L.*); the bark of the Slippery Elm (Ulmus fulva, *Michx.*); and the bark of the Basswood (Tilia Americana, *L.*).

(3) *Crystal-sacs:* the root of Yellow Dock (Rumex crispus, *L.*); the root of Rhubarb (Rheum officinale, *Baillon*); the root-bark of the Pomegranate (Punica Granatum, *L.*); and the bark of Cascara Sagrada (Rhamnus Purshiana, *DC.*).

(4) *Sacs containing crystals and mucilage:* the bulb-scales of the Squill (Scilla maritima, *L.*); the bulb-scales of Amaryllis (Amaryllis formosissima, *Willd.*); the stems of the Spiderwort

(Tradescantia Virginica, *L.*); the stems of the Green Dragon (Arisæma Dracontium, *Schott.*); and the roots of Orchis (Orchis mascula, *L.*).

(5) *Tannin-sacs:* the rhizome of Cranesbill (Geranium maculatum, *L.*) and the stem of the Horseshoe Geranium (Pelargonium zonale, *Willd.*).

I.—Let the first study be that of the rhizome of Calamus. Either the fresh rhizomes or the dried ones to be had in apothecary shops may be employed. In the latter case the material should be soaked for a few hours in water before sectioning.

Let both a transverse and a longitudinal section be mounted in a drop of water and be examined with a low power. The tissues will be found to be composed largely of parenchyma, which, like that of the Yellow Water-lily, is very loosely arranged, with large and rather regular intercellular spaces. Most of the parenchyma-cells contain small starch-grains besides protoplasm and a nucleus, but here and there among these cells are others of considerably larger size and rounded in outline, in whose interior neither protoplasm nor starch is discoverable, but which contain a refractive liquid sometimes intermixed with brownish solid matter. These cells are the secretion-sacs.

If one of the sections now be treated with Russow's potassium hydrate, the solid matter in the secretion-sacs, which before was merely brownish, becomes a deep red-brown, while the walls of the sacs are more sharply defined. Many of the sacs, it will be observed, contain none of the brown matter, but are filled, and often strongly distended, with the transparent refractive liquid, which shows no signs of saponification even after long immersion in potash solution. It may be concluded, therefore, that this liquid is probably a volatile oil. This conclusion is verified by treating fresh sections respectively with alcannin solution and with cyanin solution. Both the solid and the liquid contents of the secretion-sacs become strongly stained by these reagents. The liquid, therefore, is a volatile oil, and the brownish solid matter is a resin. Sometimes the latter appears to be crystalline; more frequently a definite structure is not discernible.

In the longitudinal section the sacs mostly present the same appearance as in the transverse section, but occasionally one appears slightly elongated or ellipsoidal.

II.—For the study of mucilage-sacs let a series of cross- and longitudinal sections of the root of the Marshmallow now be made, and be transferred to alcohol until required for use. On placing one of the cross-sections on a slide in a drop of glycerin and examining it with the low power the mucilage-sacs will be seen as transparent rounded cells rather freely but irregularly scattered through a smaller-celled parenchyma which is very rich in starch. The secretion-sacs are very numerous both in the soft tissues of the woody zone—the part, that is, within the cambium zone—and in the middle and inner bark.

If to a fresh section a drop of potassium-iodide iodine be applied, the contents of the secretion-sacs remain unstained, indicating that no proteids are present; but if, instead, a drop of the zinc-chloriodide iodine be applied, or if to the section already stained with potassium-iodide iodine a drop of sulphuric acid be added, the contents will acquire a deep-brown color, the mucilage being stained by these reagents.

The contents of the sacs appear nearly homogeneous, except that sometimes in or near the centre of the sac may be seen a few minute dark granules, probably mineral in their character. With good illumination, however, there may be observed in specimens treated with a mixture of sulphuric acid 2 parts and water 1 part, or in the specimens that have been treated with the iodine and sulphuric acid, a very delicate concentric stratification in the mucilaginous contents. An attempt has been made in the accompanying drawing (Pl. LXV., Fig. 2) to imitate the stratification-lines, but they are much more numerous and delicate than could well be shown in a drawing.

The walls of the sacs, like those of the adjacent parenchyma-cells, are unstained by anilin chloride and hydrochloric acid, but are stained blue with the iodine and sulphuric acid; they are therefore composed of cellulose. The walls have also about the same thickness as those of the adjacent parenchyma-cells.

In longitudinal section the mucilage-sacs usually appear somewhat elongated, but seldom attain a length more than twice as great as their thickness. They may be regarded, therefore, as parenchyma-cells whose protoplasmic contents have disappeared, giving place to mucilage which has come to occupy the whole interior of the cells.

III. Let the next study be that of the mucilage- and raphides-bearing sacs of Arisæma Dracontium. Having cut a supply of sections, transverse and longitudinal, preferably from the fresh stem, one of each kind may be mounted in a drop of water and be examined with the low power. In the cross-section, among the loosely-arranged parenchyma-cells, there will here and there be seen smaller cells with dark, apparently minutely granular contents. These cells are the sacs to be studied, but they will be understood much better by studying the longitudinal section. Here it will be seen that the sacs, though narrow, are often much elongated—frequently several times as long as their transverse diameter—though short ones are also found; and the solid matters in them, which in the transverse section appeared granular, is here seen to consist of great numbers of long, needle-like crystals mostly lying parallel to each other and to the length of the cells. These crystals are the so-called *raphides*.

In sections cut from fresh tissues and mounted in water as has been directed the crystals may often be seen shooting out through the end partitions into adjacent cells. This is caused by the mucilage contained in the sacs along with the crystals. The mucilage swells by the imbibition of water until rupture of the end walls, which are weaker than the lateral ones, takes place, and some of the crystals escape with the escaping mucilage.

By acetic acid the crystals are not attacked, but by hydrochloric acid they slowly disappear without effervescence; they are therefore composed of calcium oxalate.

The mucilage is stained brownish by iodine and by sulphuric acid, but not so strongly as is the mucilage of the Marshmallow. It stains also with soda-corallin.

IV.—The tannins are abundant and widely-distributed substances. They occur associated with other matters—living protoplasm, proteids, starch, etc—in various tissues, but sometimes cells appear to be especially set apart as containers for them. These cells are called tannin-sacs.

If sections of the stem of Pelargonium zonale be mounted in a drop of water and be examined, cells will be seen among the starch-bearing parenchyma-cells of the pith and cortex, which cells are filled with granular matters, but contain neither starch nor proteids. These cells are tannin-sacs, for if to a fresh section

that has not been treated with water a drop of the ferric-alum solution be applied, a blue-black precipitate will immediately be formed in them, so dense in its character as to render the sacs perfectly opaque even after the sections have been boiled in carbolic acid.

These secretion-sacs are precisely similar in shape and in the thickness and composition of their walls to the adjacent parenchyma-cells. In fact, many of the parenchyma-cells that still contain living protoplasm and starch are shown by the test to contain also considerable proportions of tannin. The blue-black color may also be seen in the meristem-cells of the cambium zone, in the soft bast-tissues of the inner bark, and even to a limited extent in the wood.

In studying the distribution of tannin in the tissues, of course the test-solution should be applied to sections that have not been treated with water or with any other tannin solvent, otherwise the tannin will have been diffused by the solvent to cells other than those in which it was secreted, and wrong conclusions may be drawn. The best results are obtained by mounting the section, dry, on a slide and then letting the ferric solution run under the cover-glass.

If to another section a drop of 10 per cent. solution of potassium bichromate be applied in a similar manner, there will be seen in the tannin-containing cells a dense reddish-brown precipitate; if to still another section a little of a solution of ammonium molybdate in an aqueous solution of ammonium chloride be applied, there will be seen a yellowish-brown precipitate in the tannin-bearing cells.

There are a few other substances besides the tannins that produce similar precipitates with these reagents, but if in any case precipitates of the color above described be attained with all three of these reagents, one may be fairly certain that the precipitates are due to the presence of tannic matters.

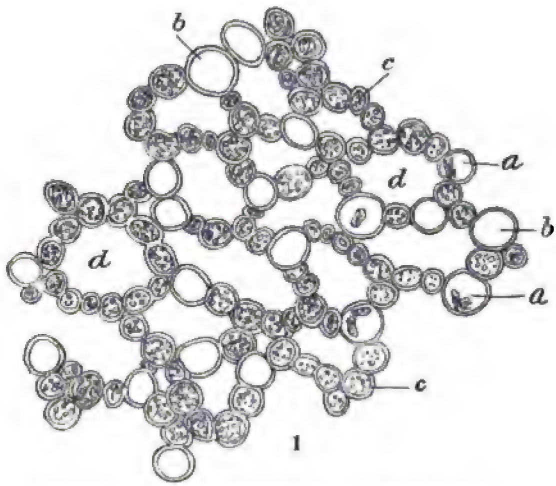
If permanent preparations are desired, thin sections which have been treated with the ferric solution may be boiled in strong carbolic-acid solution to clear them, and then be mounted directly in xylol balsam.

V.—In Exercise IV., in which was studied the petiole of the Begonia, there were observed among the collenchyma- and paren-

chyma-cells some cells which contained stellate masses of crystals which by suitable tests were proved to be composed of calcium oxalate. Agglomerated crystals of this character are exceedingly common in plants. Sometimes they are associated in the cells with proteids, starch, etc., but sometimes they occupy the cell-cavity to the exclusion of other matters.

Accompanying the bast-fibres in the bark of the Slippery Elm and Locust are very numerous short parenchyma-like cells, each usually containing a crystal of calcium oxalate. The crystals are clinorhombic, and, since they polarize beautifully, are best studied by the aid of polarized light. They are perhaps the commonest of all forms of plant-crystals.

Specimens for study by polarized light are best prepared by boiling the sections in carbolic acid to clear the tissues and then mounting them in balsam.



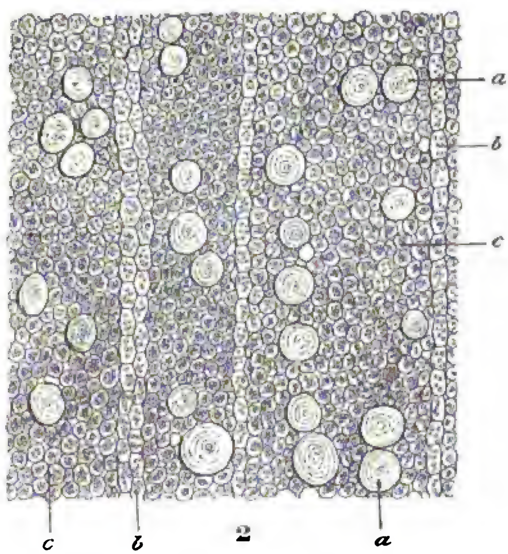


PLATE LXV., FIG. 1.—A portion of Tissue from a Transverse Section of the Rhizome of Acorus Calamus (magnified 100 diameters): *a, a*, sacs containing volatile oil and resinous matters; in *b, b* the contents are wholly hyaline; *c, c*, ordinary starch-bearing parenchyma-cells; *d, d*, intercellular air-spaces.

FIG. 2.—A portion of Tissue from a Transverse Section of the Root of the Marshmallow (magnified 100 diameters): *a, a*, mucilage-sacs (the stratification of the mucilage after treatment with dilute sulphuric acid is indicated by dotted circles); *b, b*, medullary-ray cells; *c, c*, starch-bearing parenchyma-cells. The drawing was made from the central-cylinder region of the root.

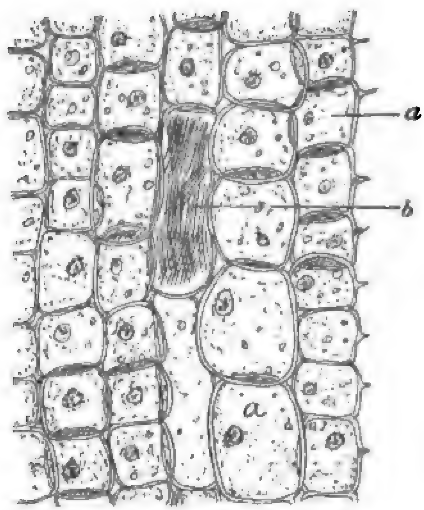


PLATE LXVI.—Small portion of Longitudinal Section of Stem of Green Dragon (magnified 100 diameters): *a*, *a*, parenchyma-cell containing protoplasm and minute starch-grains; *b*, a sac containing mucilage and numerous raphides.

EXERCISE XX.

STUDY OF INTERCELLULAR AIR-SPACES AND SECRETION-RESERVOIRS.

For the study of air-spaces selections may be made from the following plants: the fragrant White Water-lily (Nymphæa odorata, *Ait.*), the Yellow Water-lily (Nuphar advena, *Ait.*), the Bulrush (Scirpus lacustris, *L.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Bur-reed (Sparganium eurycarpum, *Engelm.*), the Pickerel-weed (Pontederia cordata, *L.*), the Water Plantain Alisma Plantago, *L.*), the Lizard's Tail (Saururus cernuus, *L.*), the Arrow-leaf (Sagittaria variabilis, *Engelm.*), the Carrot (Daucus Carota, *L.*), the Cow Parsnip (Heracleum lanatum, *Michx.*), and the Common Parsnip (Pastinaca sativa, *L.*). The most convenient parts to employ are the stems, though in most cases the leaves and roots also afford good studies.

For the study of secretion-reservoirs the following are recommended: the roots and stems of the Spikenard (Aralia racemosa, *L.*); the rhizomes of Wild Sarsaparilla (Aralia nudicaulis, *L.*); the roots of Pellitory (Anacyclus Pyrethrum, *DC.*); the young fruits of the Orange (Citrus Aurantium, *Risso*); the stem of the Compass Plant (Silphium laciniatum, *L.*); and the stems and leaves of any species of Pine or Fir.

The three umbelliferous plants mentioned in the former list also possess secretion-reservoirs which are good for study.

Intercellular air-spaces exist more or less abundantly in nearly all multicellular plants, and they probably serve the important purpose of supplying air to the interior tissues, where it is needed for respiratory purposes. In most land-plants these air-spaces are small and angular, but in aquatics they are usually of large size and often have very regular forms. They are, moreover, of two kinds—those formed by the splitting of the cell-wall that is common to two or more adjacent cells, and those formed by the destruction of some of the cells of a tissue. Those produced by the

former mode are called *schizogenous;* those by the latter mode, *lysigenous.*

In order to understand schizogenous spaces it must be known that all true tissues in an early stage of their development—that is, when they are in the form of meristem—are destitute of intercellular spaces. But later on, as the tissues develop, owing to the weakening by chemical change which takes place in the middle lamella, and to the strains induced by the rapid development and change of form of the cells, splitting takes place at the points of greatest strain, commonly in the places where several cells come together. The separation may be but slight, or it may be so complete that adjacent cells barely touch each other at a few points only.

Secretion-reservoirs and intercellular air-spaces differ from each other only in their contents.

I.—Attention is first directed to the air-spaces in the petiole of the Yellow Water-lily. Either fresh or alcoholic material may be employed. Having made several sections, longitudinal and transverse, one of each kind is mounted in water on a slide and is examined with the low power. Beneath the small-celled epidermis and the collenchyma is a larger-celled parenchyma in which there are next the outside rather small spaces; farther interior these spaces become increasingly large, until a millimetre or so beneath the surface they have many times the diameter of the cells which bound them. They are, moreover, quite regular in form, often pentagonal.

At the angles the boundary-cells are relatively considerably larger than those on the sides; they are longer also in the longitudinal section, and at considerable intervals in the column of cells constituting one of these angles there occurs a cell of altogether different shape—a freely-branching one that sends its branches into the three or four adjacent spaces. These peculiar branching cells are called *trichoblasts.* They sometimes occur in other aquatics besides the Water-lily family—in the genus Limnanthemum, for example, and in some Araceæ. It will be observed that these cells are thicker-walled than are the adjacent parenchyma-cells, and that their walls are roughened by numerous very minute crystals said by Hugo von Mohl to be crystals of calcium oxalate; but this is doubtful, as they remain apparently unchanged after boiling with strong hydrochloric acid. To see their crystalline

forms distinctly requires the use of a very high power. It is difficult to surmise what can be the use of these trichoblasts.

Removing now the cover-glass, applying one or two drops of anilin chloride, after a few moments as much hydrochloric acid, and again examining, it is found that the trichoblasts have acquired a deep-yellow color which proves them to be strongly lignified; in fact, they are about the only lignified tissue present, even the depauperated vasal bundles showing little if any lignification.

By comparing the longitudinal and the transverse sections it will be seen that the large intercellular spaces form regular channels extending long distances through the petiole or stem, only interrupted here and there by loose masses of branching cells. These cells, like the trichoblasts, are really a kind of internal hair, but, unlike the latter, are not lignified. They originate in a little saclike outgrowth from one of the cells in the wall of the passage. The sac elongates and branches profusely, and the branches are broken up into cells by the formation of transverse partitions. In favorable longitudinal sections the masses may be seen attached by the base to the wall of the passage. The walls of these hair-cells, it will be observed, are very thin, and it is possible that they are of service to the plant in absorbing gaseous food-material from the air-passages.

The air-passages in the petiole are in communication with those in the rhizome on the one hand, and with those of the leaf and with the stomata on the upper surface of the latter on the other, so that they constitute a complete system of aërating channels throughout the plant.

II.—For the study of secretion-reservoirs the rhizome of Aralia nudicaulis is selected.

Focusing upon a transverse section mounted in a drop of water, there are seen in the middle layer of the bark numerous rather large spaces resembling a good deal those of Nuphar, just studied. But if the section is of a fresh stem, there will be seen clinging to the wall of the passage some refractive droplets which are remnants of the liquid that in the living plant filled the reservoir.

It will be seen, furthermore, that the cells immediately surrounding the reservoir are smaller in size and more densely granular in their contents than those a little farther removed. They

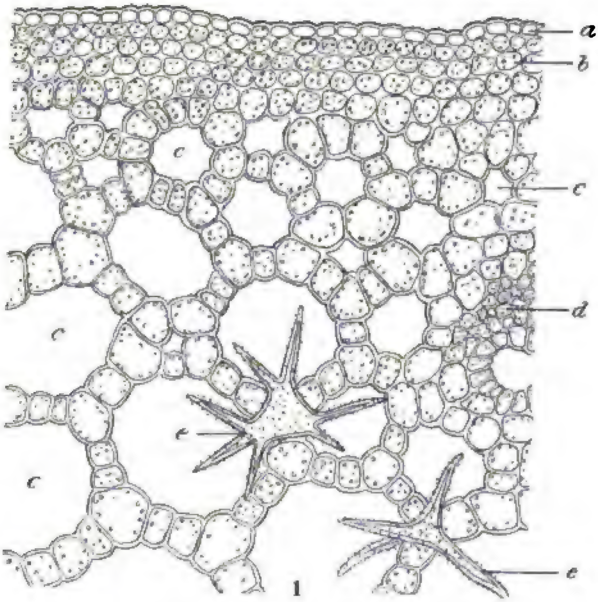
are the secreting cells, and the liquid which they secrete is discharged, by some means not yet well understood, into the reservoir where it accumulates. The contents of these reservoirs differ widely in different plants: in some they are mucilaginous, in others oleo-resinous, and in still others there may be a milk-like emulsion consisting of a mixture of resinous and mucilaginous matters. In the present instance the transparency and fluidity point to the presence of an oleo-resin; this conclusion may be confirmed by an application of the alcannin and cyanin tests. These tests would better be applied to the fresh sections, and to longitudinal sections in preference to transverse ones, for the very fluid oleo-resin too readily escapes from the reservoirs in the transverse section.

A careful study of the longitudinal section, particularly of one that has been treated with the alcannin solution in order that the reservoirs may easily be traced, shows that the reservoirs are cylindrical, unbranched, nearly straight, and that they extend long distances in the direction of the length of the rhizome.

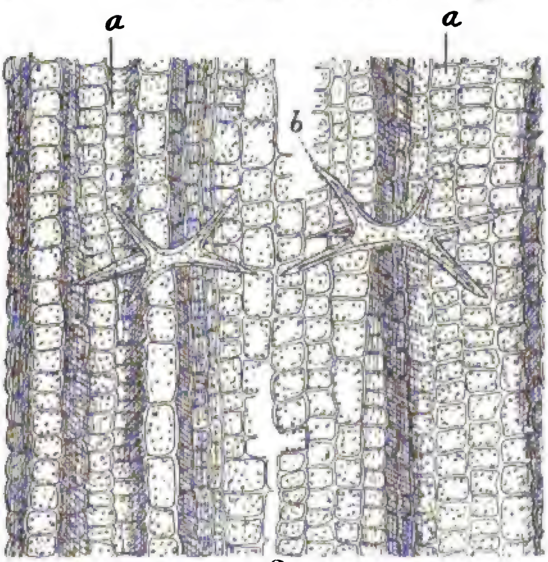
The young and growing above-ground stem affords an opportunity to study the development of this type of intercellular space, the schizogenous. A cross-section of such a stem will show clusters of three or four granular cells about a small intercellular space. Lower down in the stem, a similar section will show clusters of a like character except that the number of granular cells is larger and the space they enclose is also larger. The three or four cells with which the development began have increased, mostly by radial division, to a considerable number. This is the usual method of development of reservoirs of this class.

The air-spaces of Nuphar are also of the schizogenous variety.

If sections be made of the rind of the immature fruit of the Orange, lysigenous reservoirs will be seen in different stages of development. In the earlier stage there is only a small cluster of granular cells; in a little later one, a larger cluster, with indications that the central cells are undergoing disintegration; and in a still later one the central cells have disappeared and a drop of oil occupies their place. This area of disintegrating cells containing the oil-globule is surrounded by layers of secreting cells, some of which may in turn break down and so increase the size of the oil-cavity.



1



2

PLATE LXVII., Fig. 1.—Transverse Section of Petiole of Nuphar advena (magnified 65 diameters): *a*, **epidermis;** *b*, **collenchyma;** *c, c, c, c*, **intercellular air-spaces;** *d*, **part of vasal bundle;** *e, e*, **trichoblasts.**

Fig. 2.—Longitudinal Section of the same (magnified 65 diameters), showing some of the air-spaces cut through lengthwise, and so appearing trough-like: *a, a*, **air-spaces;** *b*, **a trichoblast with its branches projecting into air-spaces on either side.**

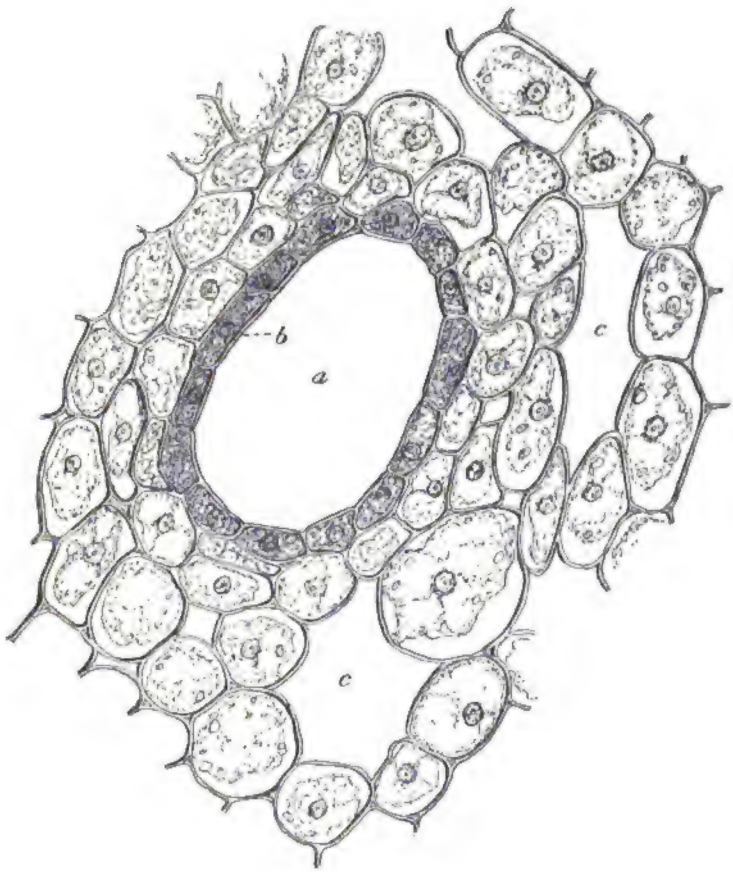


PLATE LXVIII.—Small portion of Transverse Section of Middle Bark of the Rhizome of Aralia nudicaulis (magnified about 300 diameters): *a*, secretion-reservoir; *b*, one of the secretion-cells bounding the reservoir; *c, c*, intercellular air-spaces.

EXERCISE XXI.

STUDY OF VASAL BUNDLES: THE CONCENTRIC BUNDLE.

VASAL bundles, or, as they are often called, "fibro-vascular bundles," constitute the tough, stringy tissues of plants. The harder portions of most stems and roots, and the framework of veins in leaves, consist chiefly of vasal bundles. They are pre-eminently the strengthening and conducting portions of the plant structure. A vasal bundle is usually made up of a considerable variety of tissues, and these are arranged in two groups which differ from each other quite widely in the character of their elements. One group is called *xylem* and the other is called *phloem*. Some bundles are composed of one of each of these groups; others, of two or more strands of phloem or of xylem or of both. The bundle may or may not be marked off from the surrounding tissues by a distinct layer of cells called the bundle-sheath or *endodermis*. Both phloem and xylem usually contain a variety of tissues, but different plants, as well as different parts of the same plant, differ as to the number of kinds in each. The essential tissue of the xylem, however, is tracheary tissue (which may include either tracheids or ducts or both), and that of phloem is sieve-tissue. Accompanying the tracheary tissue in the xylem are often found wood-cells and wood parenchyma-cells, ordinary parenchyma-cells, and sometimes secretion-cells of various sorts; and associated with the sieve-tissues in the phloem are usually companion-cells, often ordinary parenchyma and bast-fibres, and sometimes secretion-cells and laticiferous tissues.

Vasal bundles are classified according to the relative arrangement of the phloem and xylem masses or strands. Three different types are recognized—the *concentric*, the *collateral*, and the *radial*.

In the concentric type one of the elements, either phloem or xylem, occupies a central position and is surrounded by the other; there are hence two varieties—the one in which the xylem is cen-

tral and the phloem forms a cylinder which surrounds it, and the other in which the phloem is central, surrounded by the xylem.

In the collateral type the phloem and the xylem are located side by side. There are three varieties: the closed collateral, in which there is no meristem or cambium between the phloem and the xylem; the open collateral, in which there is a meristem-layer between the two elements; and the bi-collateral, in which there are two phloem masses with a xylem mass lying between them. Such a bundle is usually open on one or both sides; that is, between the xylem and one or both of the phloem masses is meristem-tissue.

In the radial type the xylem is arranged in the form of rays, or like the spokes of a wheel, and the phloem masses lie between the xylem-rays, usually well toward the exterior of the bundle.

The following diagrams will show at a glance the relative arrangement of phloem and xylem in the different bundles, and also the position of the meristem-layer in those bundles which possess one.

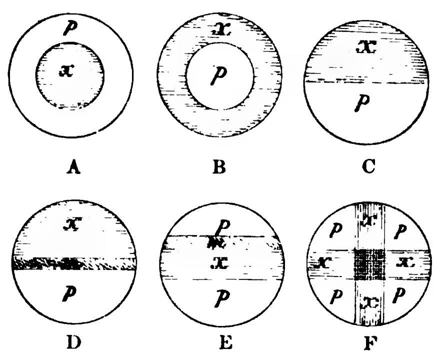


FIG. 7.—A, Concentric bundle with the xylem interior; B, concentric bundle with the xylem exterior; C, closed collateral bundle; D, open collateral bundle; E, bi-collateral bundle; F, radial bundle (p, phloem; x, xylem; m, meristem).

Let this exercise be devoted to the study of concentric bundles. Good examples for study may be found in the stem or the petiole of almost any common fern, as, for example, the Common Brake (Pteris aquilina, *L.*), the Marginal Shield-fern (Aspidium marginale, *Swartz*), the Male Fern (Aspidium Filix-mas, *Swartz*), and the Common Polypody (Polypodium vulgare, *L.*); in the stems of the Selaginellas, as Selaginella rupestris, *Spreng.*; and in the rhizomes of the Blue Flag (Iris versicolor, *L.*), the False

Solomon's Seal (Smilacina racemosa, *Desf.*), and the Sweet Flag (Acorus Calamus, *L.*).

I.—Attention is first directed to that form of the bundle in which the xylem is surrounded by the phloem. Sections, transverse and longitudinal, are made of the rhizome of Pteris aquilina, care being taken that the longitudinal section cuts through one of the bundles as nearly in the centre as possible, and preferably in the direction of its greatest width. The section will then show all of the different tissues of the bundle.

A thin transverse section is first placed upon a slide and treated with the phloroglucin reagent, which stains most of the xylem-tissues red, but leaves the phloem wholly unstained. The bundles are then easily recognized, and it will be seen that the rhizome contains a single circle of them, and within the circle, near its centre, two or three larger and considerably elongated bundles lying between two elongated masses of dark-colored sclerenchyma-fibres. It will be seen further that, while the bundles differ in size and in shape, they agree substantially in the arrangement of their parts: the red-stained ducts of the xylem are in the centre; around them is an area of soft tissues—the phloem; and separating the bundle sharply from the fundamental tissues exterior to it is a single layer of peculiar cells constituting the bundle-sheath or endodermis.

It has already been learned (Exercise XI.) that scalariform ducts abound in the xylem; in fact, this portion of the bundles is almost wholly composed of them. The only exceptions are a few spiral ducts at or near the ends of the more or less elongated xylem mass, or sometimes only at one of the ends, and a few small starch-bearing parenchyma-cells near the centre. All but the latter are strongly reddened by the phloroglucin reagent.

In order that the phloem portion of the bundle may be studied satisfactorily another preparation should be made of both the transverse and longitudinal sections. The sections should be treated with chloral-hydrate iodine, so that the thinner cell-walls may be seen distinctly and the finer starch-grains be recognized. In contact with the xylem, on its exterior, will be seen one or two tiers of small parenchyma-cells containing fine-grained starch. Immediately exterior to these are cells averaging larger in calibre and containing no starch, but rich in albuminous matters; though

it is not an easy thing to detect any sieve-plates, these are the sieve-elements. The sieve-tissues are associated with elongated, slender, almost fibrous, but unlignified companion-cells, rich in protoplasm, but not containing starch. These cells are most abundant immediately exterior to the sieve-elements. Still farther exterior, and immediately interior to the endodermis, is a layer of somewhat elongated parenchyma-cells, of rather larger calibre than the other parenchyma-cells in the phloem area. They are very rich in small-sized starch-grains.

The endodermis, which sharply limits the bundle on the outside, is composed of long, prismatic, rather thin-walled cells which in transverse section appear somewhat lengthened tangentially. Their radial walls are marked with a dark streak and are much more fragile than the other portions of the walls, so that often they are ruptured clear around the bundle in cutting a section. The endodermis when old has its walls usually more or less cutinized, and in the radial walls a little red color is developed by the phloroglucin reagent.

Exterior to the endodermis are the relatively large parenchyma-cells, rich in large-sized starch-grains.

II.—For the study of concentric bundles in which the xylem is exterior, let a series of sections, longitudinal and transverse, now be made of the rhizome of Smilacina racemosa.

The same methods may be employed as in the preceding study, or, if permanent preparations are desired, the gentian-violet and eosin process will give admirable results. The sections, made from material which has been fixed by means of alcohol or acetic alcohol, are first washed if the latter reagent has been employed, then stained with anilin-water gentian-violet, then washed, first in ordinary alcohol and afterward in absolute alcohol, then placed in eosin oil of cloves for a few minutes, and lastly mounted in xylol balsam.

As in the fern, the tracheary elements of the xylem stain with the phloroglucin and anilin-chloride reagents, while the phloem elements do not; but here, in most of the bundles at least, the former are arranged in a zone about the latter. In a few instances, however, bundles occur in which the xylem ring is incomplete; that is, it is interrupted at one point by soft tissues allied to those of the phloem part of the bundle. Such a bundle

might be regarded as a closed collateral bundle in which the xylem has nearly enclosed the phloem. In fact, since closed collateral bundles are much the more common in the stems of monocotyls, and since in some monocotyls they are found associated with concentric bundles which have a central phloem, there are good reasons for regarding the latter as only a modification of the former.

Another difference between the bundle with a central phloem and the other type of concentric bundle is the fact that there is no endodermis to separate the bundle from adjacent tissues. The parenchyma-cells in contact with the xylem elements are only a little smaller than the ordinary parenchyma-cells of the stem.

The longitudinal section shows that the xylem consists almost wholly of tracheids with small bordered pits, that the phloem consists of thin-walled sieve-tubes with very oblique plates, and that the sieve-tubes are associated with long parenchyma-cells rich in protoplasm and containing greatly elongated fusiform nuclei.

In the great majority of bundles having a central phloem the structure is substantially the same as that observed in the example just studied. This variety seldom if ever occurs elsewhere than in the stems and leaves of some monocotyls. Concentric bundles of the other type—that, namely, in which the phloem is exterior—are the kind characteristic of the stems and leaves of nearly all ferns. Only in rare instances are they found in cycads and dicotyls.

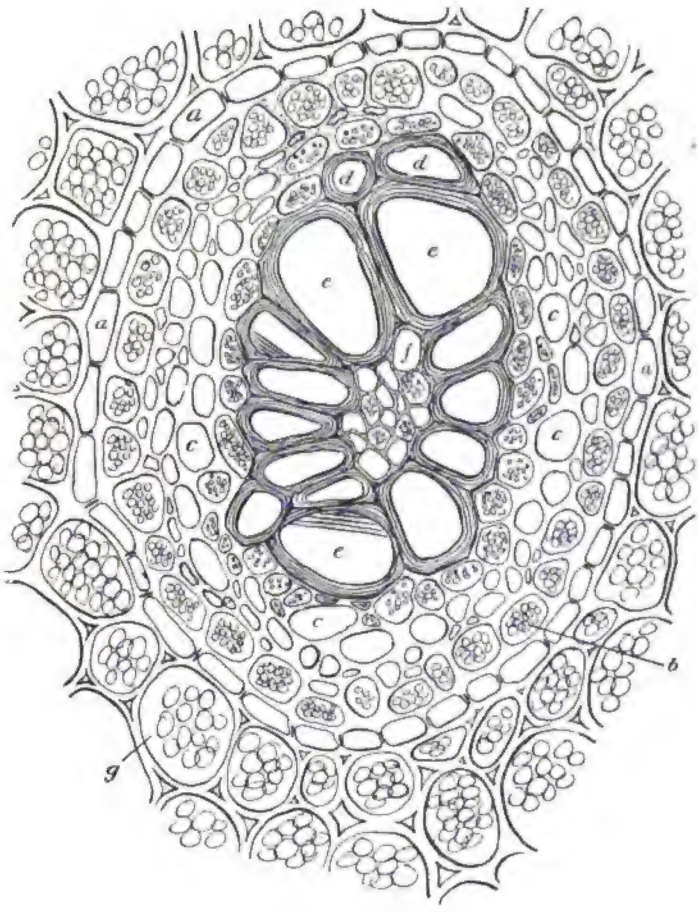


PLATE LXIX.—One of the smaller Concentric Bundles in the Rhizome of Pteris aquilina (magnified 330 diameters): *a*, *a*, *a*, cells of the endodermis; *b*, cell of starch-bearing parenchyma from the layer of cells immediately beneath the endodermis; *c*, *c*, *c*, sieve elements; *d*, *d*, spiral ducts at one end of the xylem mass; *e*, *e*, *e*, scalariform ducts in the xylem; *f*, parenchyma-cell in interior of xylem mass; *g*, parenchyma-cell from fundamental tissues exterior to the bundle, containing large starch-grains.

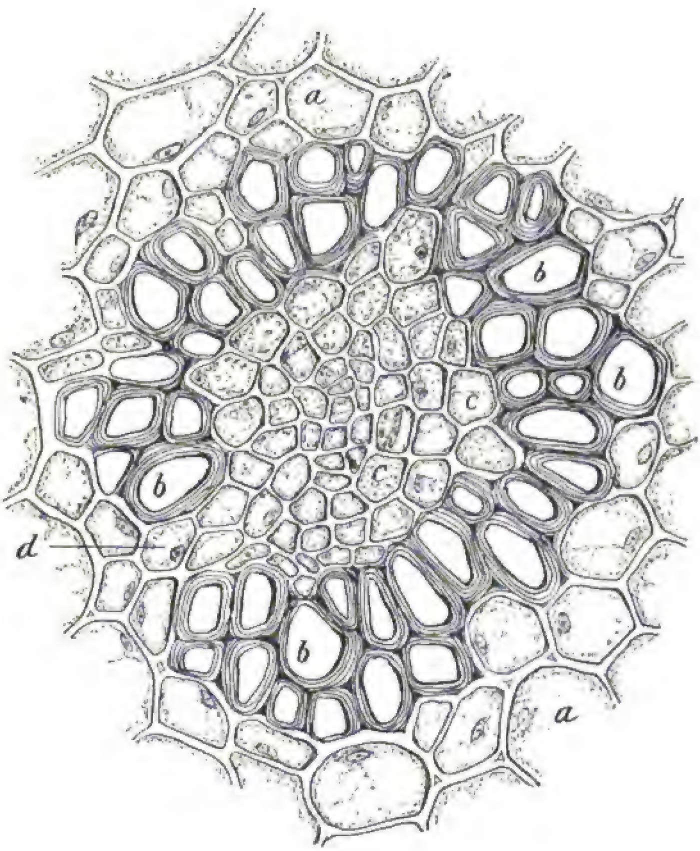


PLATE LXX.—A Concentric Bundle drawn from Transverse Section of Rhizome of Smilacina racemosa (magnified 330 diameters): *a*, *a*, parenchyma-cells exterior to bundle; *b*, *b*, pitted tracheids of xylem; *c*, *c*, sieve elements of phloem; *d*, an opening in the xylem-ring.

EXERCISE XXII.

STUDY OF COLLATERAL BUNDLES.

COLLATERAL bundles occur in the stems and leaves of a few ferns, including the genera Ophioglossum and Osmunda, and in the stems of the Equisitaceæ, but with these exceptions are confined to the stems and leaves of phanerogams, of which they are characteristic.

In the ferns mentioned, in the Equisetaceæ, and in monocotyls the bundles are usually closed; in dicotyls they are usually open. In the great majority of dicotyls the open bundles are of the sort which consists of one xylem and one phloem strand, but a few, as the members of the natural order Cucurbitaceæ, are of the bi-collateral variety.

Convenient plants for the study of closed bundles are the following: the Greenbrier (Smilax rotundifolia, *L.*), the Spider-wort (Tradescantia Virginica, *L.*), the Corn (Zea Mays, *L.*), the Bulrush (Scirpus lacustris, *L.*), the Water Plantain (Alisma Plantago, *L.*), the Arrow-head (Sagittaria variabilis, *Engelm.*), and the Yellow Nelumbo (Nelumbo lutea, *Pers.*).

Good plants for the study of open bundles are the Yellow Parilla (Menispermum Canadense, *L.*), the Virgin's Bower (Clematis Virginiana, *L.*), the Dutchman's Pipe (Aristolochia Sipho, *L'Her.*), the Sycamore (Platanus occidentalis, *L.*), the Bittersweet Solanum Dulcamara, *L.*), the Lizard's Tail (Saururus cernuus, *L.*), and the Basswood (Tilia Americana, *L.*).

For bi-collateral bundles the following plants are excellent: the Pumpkin (Cucurbita Pepo, *L.*), the Squash (Cucurbita maxima, *Duchesne*), and the Wild Cucumber (Echinocystis lobata, *Torr.* and *Gray*).

I.—For the study of a closed bundle let sections be made of the stem of Tradescantia Virginica. On staining a cross-section with the phloroglucin or the anilin-chloride reagent the bundles are readily recognized, and they are seen to be scattered without

any definite order through the stem. The bulk of the stem is made up of large-celled parenchyma rich in starch-grains, while the bundles and the sheath which encloses each of them are composed of cells of rather small diameter, containing either fine-grained starch or none at all.

The bundle-sheath, or endodermis, is composed of a single layer of cells which in transverse section look much like ordinary parenchyma-cells except that they are smaller, but in longitudinal view are observed to be considerably longer. They are also destitute of starch, and they show no cutinization. In fact, in collateral bundles generally, when an endodermis is present at all, it is less sharply defined than in concentric and radial bundles. It is more frequently wanting altogether.

The xylem in many of the bundles forms a V-shaped mass consisting almost wholly of annular and spiral ducts, but in some instances the row of ducts forms a complete circle about the phloem. Indeed, in this plant the relationship between the closed collateral bundle and that form of the concentric one in which the phloem is enclosed by the xylem is clearly shown.

Just within the endodermis, at the vertex of the V-shaped xylem mass or in the corresponding part of the concentric bundles, is usually found an intercellular space of considerable size. This is common in closed collateral bundles. At this end of the bundle are the oldest portions of the xylem, and in many monocotyls when the bundles are mature it is found that the ducts next this portion have split away from their companions and lie loose in the intercellular space. This seldom occurs, however, in Tradescantia.

The phloem portion of the bundle consists almost wholly of sieve-cells of the ordinary form and of cambiform or companion-cells with lengthened nuclei.

II.—For the study of an open collateral bundle let sections be made of the stem of Saururus cernuus, some time before the plant's blossoming season is over. It is well, in order to distinguish the parts clearly, that one set be treated either with the anilin-chloride or with the phloroglucin reagent, and another with the chloral-hydrate iodine solution. If the bundle be nearly mature and from an above-ground stem, it will be separated from the surrounding loosely-arranged parenchyma by a sheath composed of several layers of thick-walled sclerenchyma-fibres. The cells composing

this fibrous sheath are not all alike. Those facing outward in the stem and bordering the soft bast-elements on the exterior side of the bundle, being thicker-walled than the rest and constituting a thicker mass, are the bast-fibres, and those at the opposite or xylem end of the bundle, being developed into somewhat thinner-walled cells, are to be regarded as wood-cells. The thick-walled cells of the sheath which lie on the radial faces of the bundle and connect the bast-fibres with the wood-cells average of larger diameter, are somewhat thinner-walled, and possess fewer pore-canals than the cells composing the rest of the sheath. They are also less elongated when viewed in longitudinal section. In the bundles of the rhizome the structure is similar except that this portion of the sheath is composed of cells whose walls have not undergone the lignified thickening at all, lignified fibres occurring only at the outer and inner ends of the bundle.

The xylem, aside from the wood-cells mentioned, which may be accounted a part of it, is composed of elongated parenchymatous cells (wood-parenchyma), secretion-cells, and tracheary tissues. The latter consist of a few conspicuous scalariform ducts in the outer and later-formed portion of the xylem, and of smaller annular and spiral ducts in the inner and older portion.

The phloem consists of the bast-fibres already mentioned and of sieve- and companion-cells mixed with which are a few elongated secretion-cells. The secretion-cells are best seen in sections which have been stained either with the alcannin solution or with an aqueous solution of Bismarck brown.

At the junction of the phloem and the xylem are several tiers of tangentially lengthened, small, and thin-walled cells which are mostly arranged in distinct radial rows. Like the adjacent elements, they are lengthened in the direction of the longest diameter of the stem. These cells constitute the meristem- or cambium-tissue. This, as has already been stated, is not, in the strict sense of the term, a distinct tissue, but rather is made up of young cells not yet developed into tissues, some of the cells destined to form one kind of tissue, others another.

Meristem always consists of very thin-walled cells, rich in protoplasm, with walls of cellulose, and without intercellular spaces. The cells are also, until the vegetative work of the plant is completed, in a state of active division.

The stem of Saururus is herbaceous and dies down at the close of the season of growth, and although the activity of the cambium continues until flowering, it soon after ceases, and the bundles, before the death of the stem, become closed. In the stems of dicotyl shrubs and trees, however, the stoppage of growth in the cambium zone is only temporary; in the spring activity is resumed, and so the bundles increase in length in a radial direction year by year.

III.—For the study of bi-collateral bundles let sections be made of the stem of Cucurbita Pepo, thirty or forty centimetres back of its apex, where the bundles will be found fairly mature.

The xylem portion of the bundle is easily recognized by the very large ducts which occupy its outer four-fifths or more. These ducts have already been studied (see Exercise XI.). In the interior portion of the xylem—that is, in that portion which faces toward the centre of the stem—which is also the first-formed portion, are a number of scattered ducts of much smaller size, which are mostly spiral and annular. The tissue which, in the xylem, fills in the spaces between the ducts consists chiefly of elongated parenchymatous cells with thin walls, and a few cells somewhat thicker-walled and more fibrous in their character, but hardly sufficiently fibrous to be called wood-cells.

At the outer and inner ends of the bundle are the phloem masses, consisting of large and well-developed sieve-cells and smaller companion-cells, both of which have already been studied (see Exercise XIII.). No proper bast-fibres occur in the bundle.

Between the exterior phloem mass and the xylem is a band of meristem-tissue, several layers of cells thick, and between the inner end of the xylem and the inner phloem mass is a somewhat thinner layer of the same tissue. Such a bundle, therefore, increases in length in a radial direction by the formation of new cells in both these layers, some of the cells when mature contributing to the thickness of the xylem tissues, and others to that of the phloem masses.

It is very instructive to compare sections of bundles in the older with those in the younger portions of the stem. It will then be seen how much the bundles have increased in length, and in what portions of the bundles the greatest increase of cells has taken place.

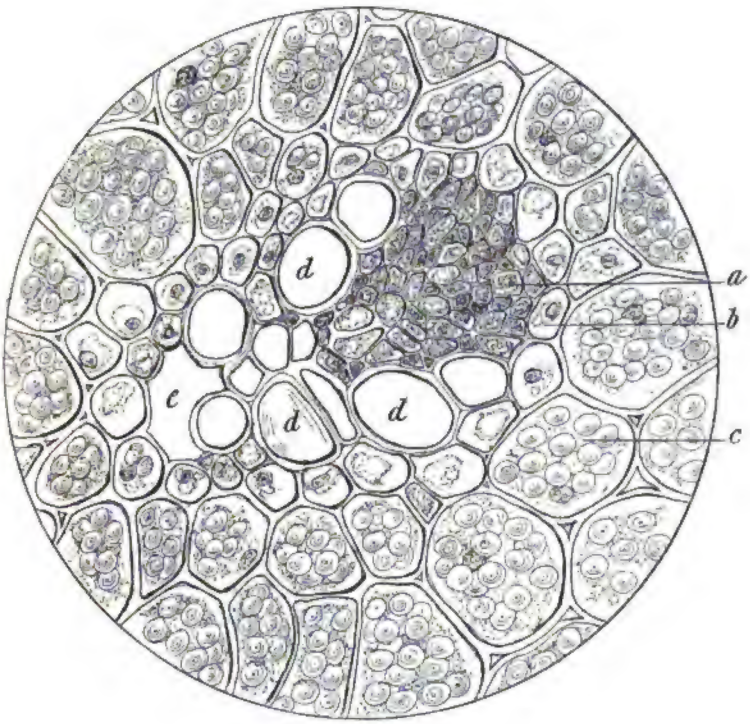


PLATE LXXI.—Closed Collateral Bundle in the Stem of Tradescantia Virginica (magnified 155 diameters): *a*, one of the sieve-cells; *b*, one of the sheath-cells; *c*, one of the starch-bearing parenchyma-cells exterior to the bundle; *d*, *d*, *d*, scalariform ducts in the xylem area of the bundle; *e*, a large schizogenous intercellular space at the older portion of the xylem end of the bundle.

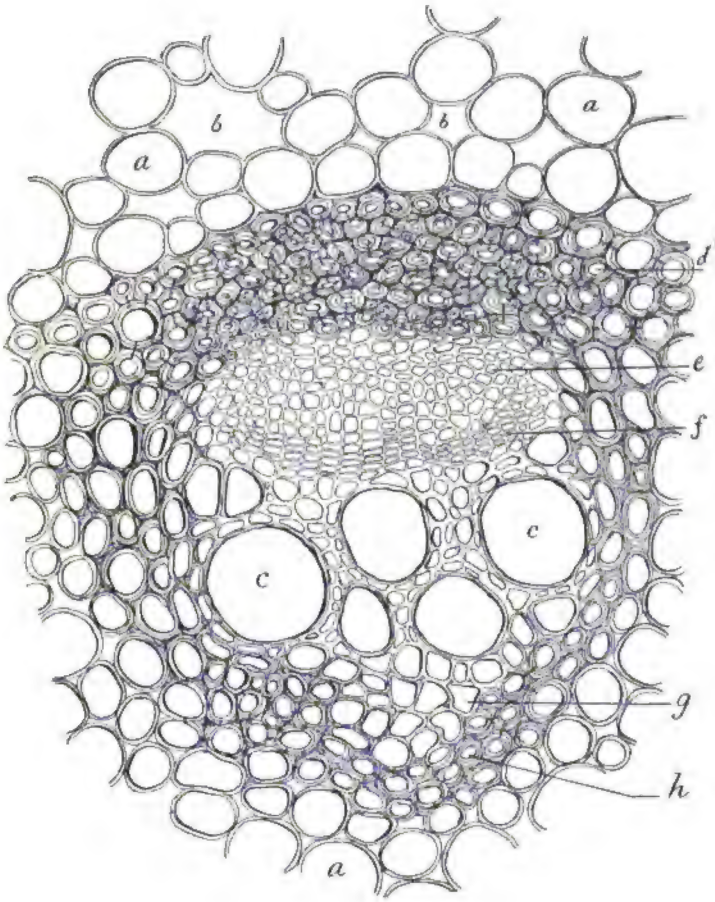


PLATE LXXII.—An Open Collateral Bundle from the above-ground Stem of Saururus cernuus (magnified 210 diameters): *a, a,* parenchyma-cells of the fundamental tissues exterior to the bundle; *b, b,* intercellular spaces, *c, c, c,* large ducts in the younger portions of the xylem; *d,* bast-fibres; *e,* soft bast-tissues; *f,* meristem layer; *g,* spiral duct in older part of xylem; *h,* wood-cell.

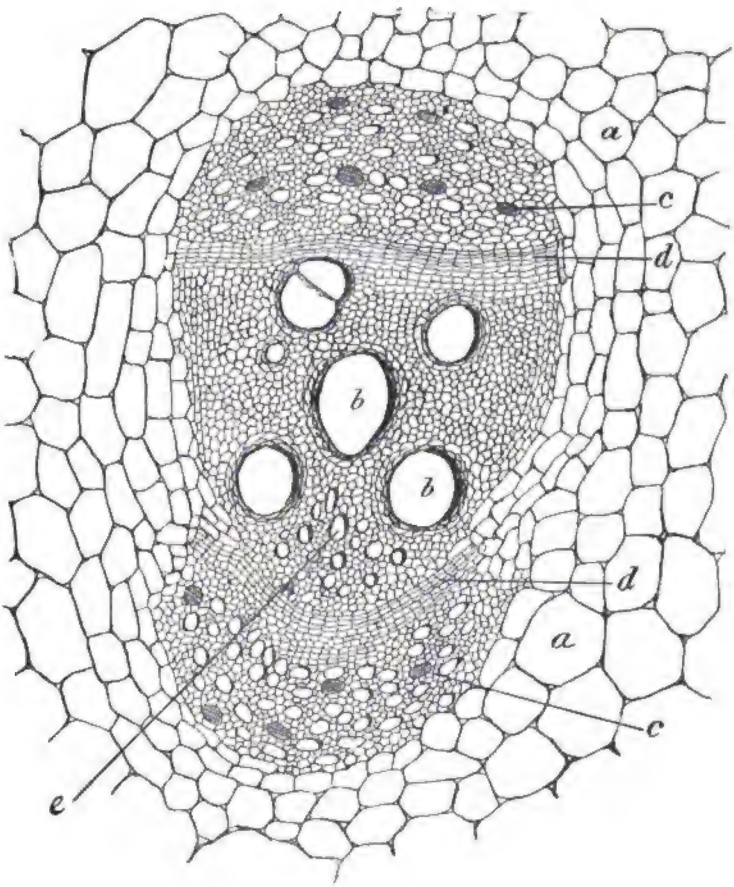


PLATE LXXIII.—Bi-collateral Bundle from Stem of Cucurbita Pepo (magnified about 50 diameters): *a*, *a*, parenchyma-cells exterior to bundle; *b*, *b*, large reticulate and pitted ducts in xylem; *c*, *c*, sieve-cells in outer and inner phloem respectively; *d*, *d*, outer and inner meristem layers respectively; *e*, small spiral or annular duct in older part of xylem.

EXERCISE XXIII.

STUDY OF RADIAL BUNDLES.

RADIAL bundles are characteristic of the roots of all phanerogams and pteridophytes; they occur also in the stems of the Lycopodiaceæ. As has already been stated, their peculiarity consists in the fact that the xylem masses are arranged in a radiate manner with phloem masses between the rays; but they present a very considerable variety of forms, differing from each other not only in the number of rays, but in their length, in the degree of lignification, and in the structure of the pericambium-layer and the endodermis. There are bundles that have as few as two xylem-rays, and others that have as many as forty or fifty. The different varieties are named according to the number of rays they possess, those with two rays being called diarch, those with three rays triarch, and so on. The diarch bundle sometimes so closely approaches the concentric in structure that careful study is required to distinguish them.

The radial bundles in the roots of dicotyls and gymnosperms usually differ from those in the roots of monocotyls in being fewer-rayed and in having a thinner-walled endodermis, though the rule has its exceptions.

The roots of the following plants afford convenient studies: the Creeping Crowfoot (Ranunculus repens, *L.*), the Mayapple (Podophyllum peltatum, *L.*), the Black Cohosh (Cimicifuga racemosa, *Nutt.*), the Culver's Root (Veronica Virginica, *L.*), the Amaryllis (Amaryllis formosissima, *Willd.*), the Onion (Allium Cepa, *L.*), the Sweet Flag (Acorus Calamus, *L.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Skunk Cabbage (Symplocarpus fœtidus, *Salisb.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Yellow Lady's Slipper (Cypripedium pubescens, *Willd.*), the Maize (Zea Mays, *L.*), the Sarsaparilla (Smilax officinalis, *Kunth*), and the Moonwort Fern (Botrychium Virginianum, *Swartz*).

I.—For the first part of this study let sections be made of the root of Podophyllum peltatum.

In sectioning, the roots should be held between pieces of pith, according to the directions given for sectioning thin objects in the Introduction to Part II. Excellent sections, both longitudinal and transverse, may be produced by this method. The sections are best handled by means of a moistened camel's-hair brush.

One set of sections would best be treated with the anilin-chloride reagent to differentiate the lignified xylem-elements; but in order that all the cells of the bundle may be seen distinctly another set should be treated with chloral-hydrate solution and be heated so as to clear the tissue of starch; or permanent preparations of great beauty may be made by bleaching the sections with Labarraque's solution, washing them thoroughly, and staining first with iodine-green and then, after thorough washing, with ammonia carmine. The sections are then, after gradual anhydration by the alcohol process and clearing with oil of cloves, mounted in xylol balsam.

The bundle will usually be found to be pentarch, but sometimes it is hexarch; more rarely it has fewer than five rays, being at times even triarch. The xylem-rays have at their exterior terminations very narrow reticulate ducts, while in the later-formed portions of the rays farther interior the ducts are larger and are mostly scalariform. The central portion of the bundle may or may not contain a few scattered ducts, but the greater portion is composed of elongated parenchymatous cells.

The phloem-tissues, which, as usual, consist chiefly of sieve- and companion-cells, are located between the xylem-rays, well toward the outer extremities of the latter, and are separated from them by two or three layers of thin-walled parenchyma-cells on either side. In sections which have been cleared with any of the usual clearing agents, as potassium-hydrate or chloral-hydrate solution, the sieve- and companion-cells may readily be distinguished from the other tissues by their glistening walls.

Immediately interior to the endodermis is a zone consisting of two layers of thin-walled cells of rather larger calibre than either the phloem-cells or the endodermal cells, and containing small quantities of fine-grained starch. This zone is the pericambium-layer or phloem-sheath. Its cells retain the power of

fission, and it is in this layer, opposite the end of a xylem-ray, that a root-branch has its origin.

As in the concentric bundle, the radial bundle is enclosed by a well-developed endodermis which always consists of a single layer of cells, and which in this as in most other roots is composed of tangentially elongated cells. In this case, as usually in dicotyls, the cells composing the endodermis remain thin-walled and are but slightly if at all cutinized.

II.—Let a series of transverse and longitudinal sections of a root of Cypripedium spectabile be cut and subjected to the same treatment.

In this case the bundle will usually be found to be octarch. The xylem-rays when the bundle is mature extend nearly or quite to the centre, about which are rather numerous reticulate ducts of large size, together with thick-walled xylem-elements of narrower calibre. The outer portions of each ray, which are composed of narrow reticulate and spiral tracheids, are bordered by thick-walled, lignified cells instead of the usual thin-walled parenchyma-cells, and these thick-walled cells extend clear to the endodermis, so that the pericambium is interrupted in places. The latter nowhere forms more than a single layer of cells, and seldom an interrupted chain of more than five cells. There are usually about this number of pericambium-cells opposite each phloem mass, and from one to three at the end of each xylem-ray.

Another peculiarity is seen in the structure of the endodermis. Opposite the lignified cells of the xylem-rays and their border of thick-walled cells the endodermis is composed of tangentially elongated but very thin-walled cells, while opposite the outer extremity of each phloem mass the endodermal cells have their walls much thickened, but by no means equally so. The outer wall is quite thin, while the radial walls are somewhat thickened and the inner ones are excessively so. In consequence of this the thickened portions look like a crescent with the horns turned outward.

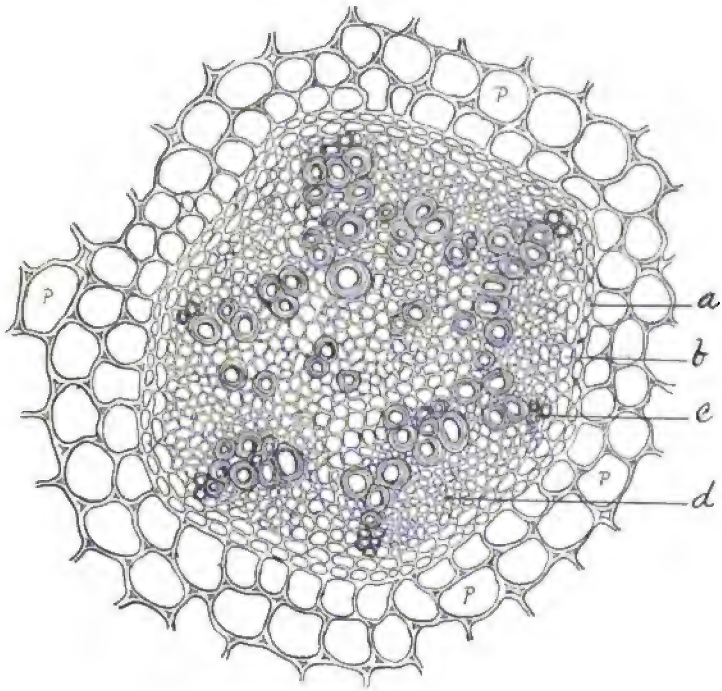


PLATE LXXIV.—Radial Bundle from the root of Podophyllum peltatum (magnified 175 diameters): *a*, endodermis; *b*, pericambium; *c*, end of one of the xylem-rays; *d*, phloem mass; *p*, *p*, *p*, *p*, parenchyma-cells of the fundamental tissues exterior to the bundle.

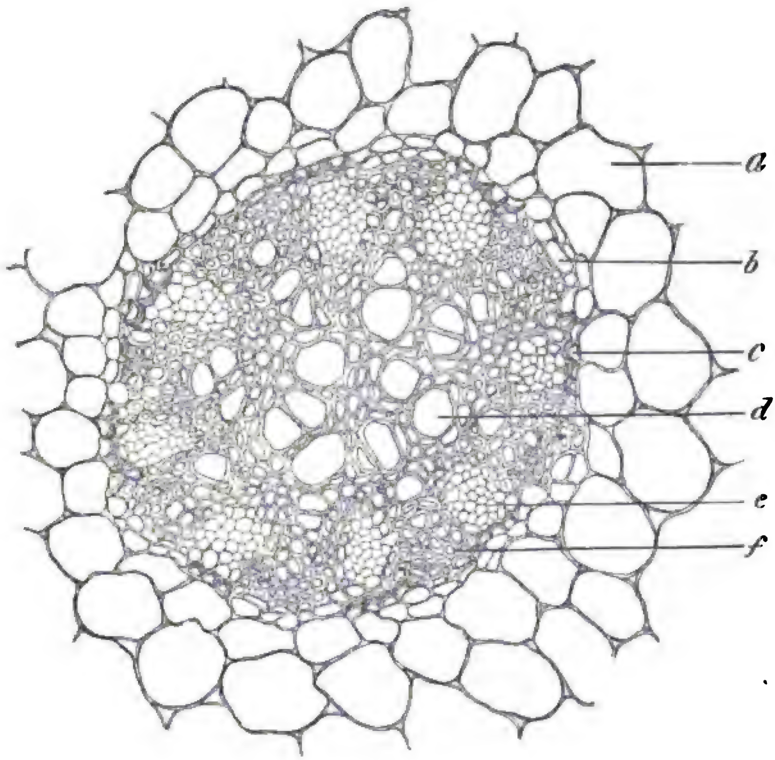


PLATE LXXV.—Radial Bundle of Root of Cypripedium spectabile (magnified 115 diameters): *a*, parenchyma-cell exterior to bundle; *b*, endodermal cell opposite end of a xylem-ray: it is tangentially elongated and thin walled; *c*, a thick-walled endodermal cell opposite the end of a phloem mass; *d*, large reticulate duct near centre of bundle; *e*, phloem mass; *f*, lignified cells bordering xylem-ray.

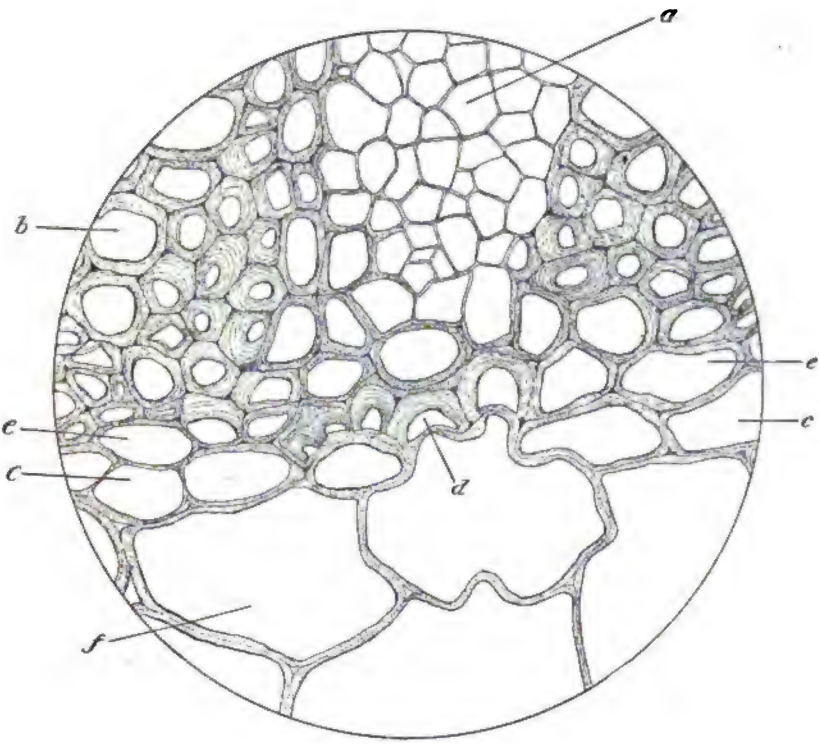


PLATE LXXVI.—Small portion of one of the Radial Bundles of Cypripedium root (magnified 500 diameters): *a*, a sieve-cell of the phloem; *b*, one of the ducts in a xylem-ray; *c*, *c*, thin-walled endodermal cells opposite the ends of xylem-rays; *d*, a thick-walled endodermal cell opposite phloem mass; *e*, *e*, pericambium-cells; *f*, parenchyma-cell exterior to bundle.

EXERCISE XXIV.

STUDY OF ROOTS.

Two different types of root structure exist in the higher plants —that observed in monocotyls, and that observed in dicotyls and in gymnosperms. These two types differ from each other less in their original structure than in their after-development or in the secondary changes which they undergo. In general, it may be said that the roots of monocotyls possess a central radial bundle, usually many-rayed and enclosed by a thick-walled endodermis, which bundle undergoes few secondary changes, while the roots of dicotyls and gymnosperms possess a central radial bundle, usually few-rayed and enclosed by a thin-walled endodermis, which bundle undergoes profound secondary changes.

Monocotyl roots favorable for study may be observed in the following plants: the Amaryllis (Amaryllis formosissima, *Willd.*), the Sarsaparilla (Smilax officinalis, *Kunth*), the Pothos (Pothos pertusa, *Roxb.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Blue Flag (Iris versicolor, *L.*), the Sweet Flag (Acorus Calamus, *L.*), the Yellow Lady's Slipper (Cypripedium pubescens, *Willd.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Reed Bent Grass (Calamagrostis longifolia, *Hook.*), and the Maize (Zea Mays, *L.*).

The roots of the following dicotyls afford good studies: the Buttercup (Ranunculus septentrionalis, *Poir.*), the Beet (Beta vulgaris, *Willd.*), the Carrot (Daucus Carota, *L.*), the Culver's Physic (Veronica Virginica, *L.*), the Monkshood (Aconitum Napellus, *L.*), and the Black Cohosh (Cimicifuga racemosa, *Nutt.*).

From among gymnosperms, the roots of any species of Pine or Fir may be studied.

I.—In the first part of this study attention is directed to the way the root grows in length and the structure it shows at its apex. For the purpose of elucidating these points the root of

Calamagrostis longifolia is selected. The young root-tips of this grass are of such a size that sections of them may be made without much difficulty by placing one of the root-tips between two flat pieces of cork that will serve to direct the razor-blade lengthwise of the root through its middle. A common bottle-cork a centimetre in diameter and a centimetre and a half long will serve the purpose well. After halving the root-tip in the manner directed the halves may again be cut in a similar way until the sections are sufficiently thin for study. If the section has passed almost exactly through the middle of the root, it will, when properly mounted and examined with the low power, present an appearance similar to that shown in Plate LXXVII.

The structure is well shown if the section be treated with chloral-hydrate iodine. It is also beautifully shown by staining the section with Grenacher's alum carmine, anhydrating it, and mounting it in balsam.

There are three regions into which every root is divided. These, in transverse view, present a series of concentric zones: on the exterior the epidermal, next interior the cortical, and in the centre the central-cylinder region. The first is usually thin, composed at most of but a few layers of cells; the second is commonly of considerable thickness, composed chiefly of parenchymatous tissues; and the third, also usually rather thick, is the region which contains the central radial bundle. The bundle is in fact coextensive with the central cylinder. In Plate LXXVII. these regions are indicated at *e*, *b*, and *a* respectively. In the young root, of course (and in the growing root that portion next the tip is always young), the tissues in these regions are still in a nascent state, the cells are still active, and distinct tissues have not yet been developed. In this condition names different from those applied to the mature structures are given to the respective regions: the nascent epidermal region is called the *dermatogen;* the nascent cortex, the *periblem;* and the nascent central cylinder, the *plerome.*

The root has at its extremity a cap quite easily distinguishable from the rest, and indicated in Plate LXXVII. at *h*, *h'*, and *i*. All these different layers, including the cap, have their origin in the region about *g* (Pl. LXXVII.), where there is a mass consisting of a large number of meristem-cells. It will be noticed that the cells

on all sides of this area are arranged in rows focusing at this growing-point. At *i* is the younger portion of the root-cap, with its cells still arranged as just described, while at *h* and *h'* are the older portions of the cap, composed of larger and thicker-walled cells in which the radial arrangement has become obscured. At the surface of the cap the cells are even becoming disintegrated. At *f* is a transparent area consisting of the thickened and mucilaginous outer wall of the epidermis. At *d* is distinguishable, though not without some difficulty, the endodermis, constituting the inner layer of the cells of the cortex. At this stage in the development of the endodermis it is clear that it belongs to the cortex rather than to the central cylinder. At *c* is a row of cells already considerably larger than the neighboring ones: they constitute the beginnings of a duct. Higher up in the root it would be found that the cells composing the row had lost their protoplasm, that their walls had acquired distinct markings, and that the transverse partitions had wholly or partially disappeared.

The student should carefully compare a transverse section of the older portion of a root with the longitudinal section just studied, trace the correspondence of parts, and also note the changes which have developed during growth.

In nearly all phænogamous plants the structure and growth of the root at its apex resemble those of Calamagrostis; but in some of the higher cryptogams (the Ferns and Equisetæ) the growing-point or *punctum vegetationis*, corresponding to *g* in the drawing, consists of a single cell instead of a cluster of cells. In these plants all the tissues of the root—root-cap, epidermis, cortex, and central cylinder—originate by the successive cutting off of cells from a somewhat triangular generative cell located at the punctum vegetationis.

II.—Let now the secondary changes that usually take place in the central cylinder of the roots of dicotyls and gymnosperms be studied in the adventitious roots which spring from the rhizome of Cimicifuga racemosa.

In a root twelve or fifteen centimetres long, sections made a centimetre or two back of the apex will show scarcely any change; three centimetres or so back of the apex, considerable changes will be observed; and four or five centimetres back,

very decided changes. Let such a series of sections be prepared and be treated with chloral-hydrate iodine solution.

Focusing with a low or moderate power on a section from near the apex of the root, the usual structure of a radial bundle will be observed. Different roots of the species will vary as to the number of rays, some being triarch, others tetrarch, and still others pentarch, but all agree in possessing a central pithy portion, short xylem-rays with the smaller ducts pointing toward the exterior, rounded masses of phloem between the exterior ends of the xylem-rays and separated from them by two or three layers of parenchyma, and a pericambium consisting of about two layers of cells. Separating the bundle from the cortex is also a distinct endodermis.

A section made at a point a little higher up on the root shows that the bundle has increased in size. The cells of the endodermis have become more numerous by radial division; the ends of the xylem-rays are now farther removed from the endodermis, proving that the intervening tissues have increased by division of the cells; new ducts have formed on either side of the interior ends of the xylem-rays, and evidences are seen, from the increase in size of some of the cells, that still others are forming farther interior; and a layer of meristem is traceable around the exterior end of each xylem-ray, along its sides, and extending across from the base of one ray to the next, behind each phloem mass, and so forming a complete but wavy girdle—in fact, a cambium zone—running in and out between phloem and xylem. Furthermore, evidences are seen, in the increased quantity of starch in the several layers of cells immediately interior to the endodermis, that these cells are passing over into the condition of permanent tissues.

If now a section from a still older portion of the root be examined, more decided changes will be seen. The endodermis is still traceable, but is much farther removed from the centre and encloses a much larger bundle. The parenchyma-cells exterior to the endodermis, by reason of the pressure due to the growth in the area interior to the endodermis, have become tangentially stretched, and so also have the starch-bearing cells interior to the endodermis. In the interior of the bundle, in the specimen from which the drawing was made (Pl. LXXIX.), four broadly wedge-

shaped medullary rays separate laterally four broad, somewhat wedge-shaped xylem masses which meet at the centre to form a figure resembling a Maltese cross. At the outer extremity of each xylem mass is a triangular mass of phloem with its broad base resting upon a layer of cambium which separates the phloem from the xylem and is continued across the medullary ray to the next arm of the cross, and so around. The cambium zone, though still somewhat wavy, has become less so than in the last section. At the inner angle of the medullary rays are still recognizable the four original xylem-rays, and at the outer ends of the triangular masses of phloem are the original phloem masses which in the young bundle lay between the ends of these rays. It will be seen that there must have been an enormous new growth of cells in the cambium zone to form the new wood wedges and medullary rays and to push so far outward the phloem masses and the boundaries of the bundle.

The root of Cimicifuga may be taken as illustrating in a simple way the most important features of the secondary changes which occur in the roots of the great majority of dicotyls and gymnosperms. These changes sharply distinguish the roots of these two groups of plants from those of monocotyls and vascular cryptogams, in which no cambium zone is formed.

The root of Cimicifuga, however, differs in some minor particulars from the roots of many other dicotyls and from those of gymnosperms. For example, the broad medullary rays above described are the only ones recognizable in Cimicifuga, while in the roots of many other plants of its sub-class, and in those of gymnosperms, the newly-formed phloem and xylem masses are crossed by secondary medullary rays often narrower than the primary ones, but similarly arranged, so that the new formations are divided into a series of radially-arranged bundles like the open collateral ones in the stems of the same plants. In fact, to the eye, often the most conspicuous difference between the mature stem and the mature root of a dicotyl or a gymnospermous plant is the presence of a pith in the former and its absence in the latter.

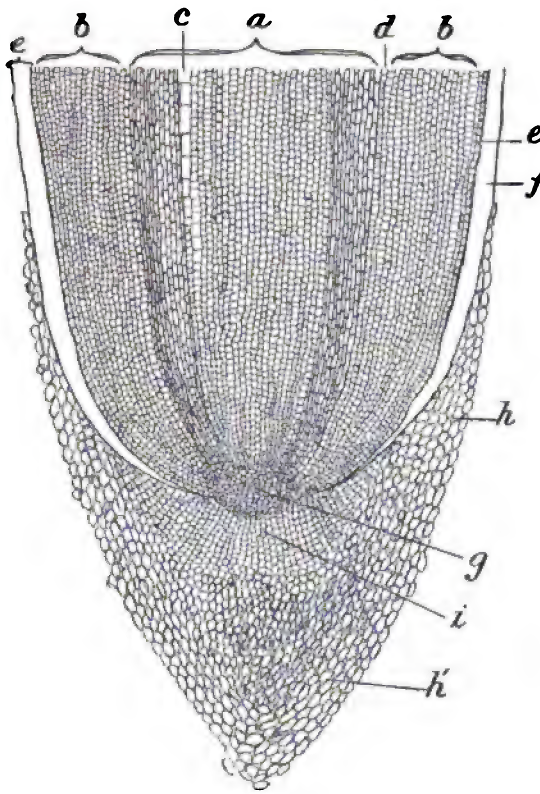


PLATE LXXVII.—Longitudinal Section through the centre of the Root-tip of Calamagrostis longifolia (magnified about 100 diameters): *a*, plerome-cylinder; *b*, *b*, periblem; *e*, *e*, dermatogen; *c*, duct in process of formation; *d*, endodermis; *e*, thickened, mucilaginous outer wall of forming epidermal layer; *g*, punctum vegetationis; *h*, *h'*, older portions of root-cap; *i*, younger portion of root-cap still showing radial arrangement of its cells.

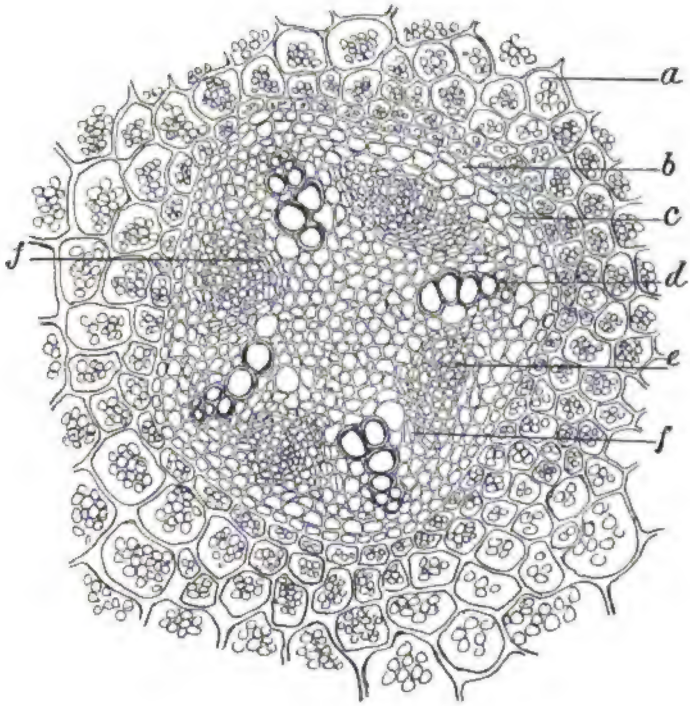


PLATE LXXVIII.—Part of Transverse Section of younger portion of Root of Cimicifuga racemosa, showing radial bundle not much changed by secondary formations (magnification, 100 diameters): *a*, starch-bearing parenchyma-cell of the cortex; *b*, endodermis; *c*, pericambium; *d*, small ducts at the outer extremity of one of the four xylem-rays; *e*, phloem mass; *f*, *f*, meristem tissue beginning to form back of the phloem mass and between it and the xylem-rays on either side.

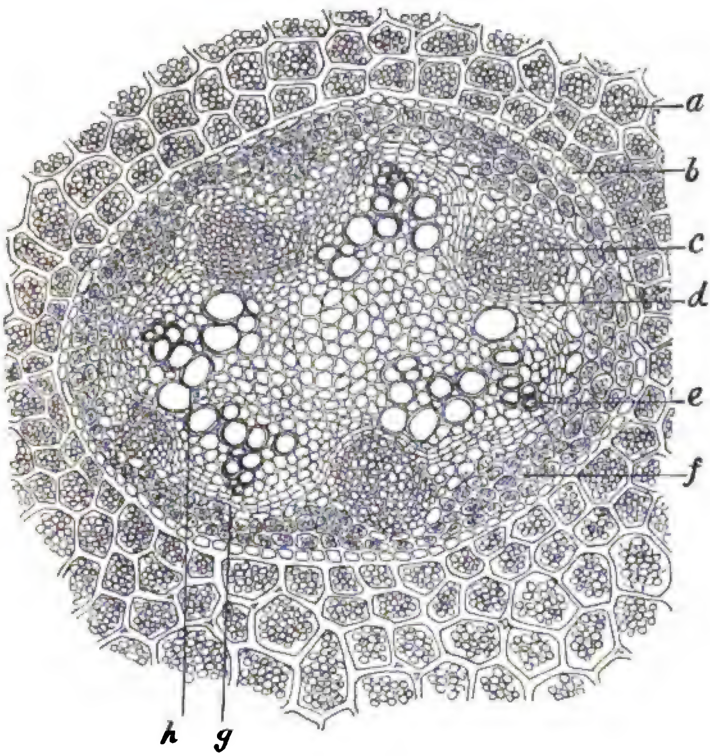


PLATE LXXIX.—Section from an older portion of the Root of Cimicifuga racemosa, showing the secondary changes much farther advanced (magnification the same as in the previous figure): *a*, starch-bearing parenchyma-cell of cortex; *b*, endodermis; *c*, one of the four phloem masses; *d*, meristem formed back of one of the phloem masses; *e*, extremity of one of the xylem-rays; *f*, starch-bearing cells interior to endodermis; *g*, cambium formed over the end of a xylem-ray, and continued into a wavy girdle running in and out between the phloem and xylem masses; *h*, new ducts that have been formed behind a phloem mass.

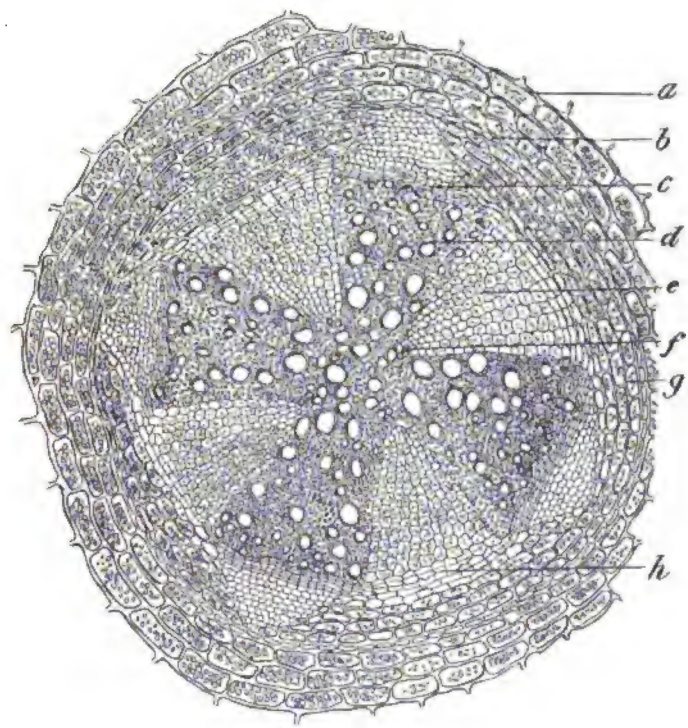


PLATE LXXX.—Part of section of still older portion of a Root of Cimicifuga racemosa (magnification about 50 diameters): *a*, a starch-bearing parenchyma-cell of the cortex; *b*, endodermis; *c*, cambium; *d*, duct in secondary xylem; *e*, one of the starch-bearing cells of the broad, wedge-shaped medullary ray; *f*, outer extremity of one of the four original xylem-rays; *h*, cambium of medullary ray.

EXERCISE XXV.

DIFFERENT TYPES OF STEMS.

Among vascular cryptogams and phanerogams four different types of stem structure may be recognized: the fern type, the club-moss type, the monocotyl type, and the dicotyl type.

The fern type may be studied in the rhizomes of the following ferns: Polypodium vulgare, *L.*, Pteris aquilina, *L.*, Aspidium Thelypteris, *Swartz*, A. spinulosum, *Swartz*, A. marginale, *Swartz*, and A. Filix-mas, *Swartz.*

The club-moss type may be studied in the following species of Lycopodium: L. clavatum, *L.*, L. Selago, *L.*, L. inundatum, *L.*, and L. obscurum, *L.*

The monocotyl type is conveniently studied in any of the following plants: the Greenbrier (Smilax rotundifolia, *L.*), the Asparagus (Asparagus officinalis, *L.*), the False Solomon's Seal (Smilacina racemosa, *Desf.*), the Solomon's Seal (Polygonatum biflorum, *Ell.*), the Tiger Lily (Lilium tigrinum, *Ker*), the Wild Yellow Lily (Lilium Canadense, *L.*), the White Hellebore (Veratrum viride, *Ait.*), the Pickerel Weed (Pontederia cordata, *L.*), the Spiderwort (Tradescantia Virginica, *L.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Indian Corn (Zea Mays, *L.*), and the Wheat (Triticum vulgare, *Villars*).

The dicotyl type is well illustrated in the stems of any of the following: the Black Cohosh (Cimicifuga racemosa, *Nutt.*), the Cocculus (Cocculus Carolinus, *DC.*), the Yellow Parilla (Menispermum Canadense, *L.*), the Virgin's Bower (Clematis Virginiana, *L.*), the Basswood (Tilia Americana, *L.*), the Silver Maple (Acer dasycarpum, *Ehrh.*), the Licorice (rhizome) (Glycyrrhiza glabra, *L.*), the Witch Hazel (Hamamelis Virginiana, *L.*), the Parsnip (Pastinaca sativa, *L.*), the Pumpkin (Curcurbita Pepo, *L.*), the Pipe Vine (Aristolochia Sipho, *L'Her.*), the Sycamore (Platanus occidentalis, *L.*), the Lizard's Tail (Saururus cernuus, *L.*), and, among gymnosperms, the White Pine (Pinus Strobus, *L.*), the

Tamarack (Larix Americana, *Michx.*), and the Bald Cypress (Taxodium distichum, *Richard.*).

I. THE FERN TYPE.—Let cross-sections be made of the rhizome of Pteris aquilina, and, that the vasal bundles may well be seen, let one of the sections be treated with the phloroglucin reagent. The appearance presented under a very low magnifying power is that shown in Figure 1 (Pl. LXXXI.). At the outside is the epidermis, composed of a layer of thick-walled cells whose walls are colored deep-brown, and immediately interior to it are several tiers of thick-walled cells, also colored brown, constituting the *hypoderma*. Together these constitute the darkly shaded area indicated at *a*, *a* in the drawing. A hypoderma is very commonly, though not always, developed in the stems of ferns.

Interior to the hypoderma is a rather thick portion of cortex consisting almost wholly of thin-walled parenchyma-cells containing starch. It may, however, contain a few small clusters of dark-colored sclerenchyma-fibres as indicated at *b*. There is in this case no sharp line of demarkation between the central cylinder and the cortex. The central cylinder, however, is the area which includes the vasal bundles, no bundles being found in the cortex save where a branch passes off from one or more of the bundles to supply a root or a leaf. If an imaginary line be drawn around the exterior bundles, which form a circle, in such a manner as to touch the outside of each of them, this line would form the boundary between the cortex and the central cylinder. There are thus the same three regions in the stem as in the root: the epidermal region, the cortical region, and the central-cylinder region.

Most of the vasal bundles are elongated, those forming the circle being elongated in a tangential direction, and the two large bundles near the centre being elongated in the direction of the longer diameter of the somewhat flattened stem.

Interior to the circle of bundles and exterior to the large central bundles are two long, somewhat curved masses of dark-colored sclerenchyma-fibres, the larger one of the two being indicated at *e* in the drawing.

The vasal bundles, as has already been learned (Exercise XXI.), are of the concentric type, and of that form of it in which the

xylem is located centrally. If longitudinal sections of the stem were to be studied, it would be found that the bundles in the circle do not remain wholly independent of each other throughout their course, but that they occasionally anastomose, and besides this send off branches to supply the leaves.

There are some features in the structure of the stem of Pteris aquilina which are not found in all fern stems, and which are therefore not essential to the type.

What, then, are the essential features of the type? They consist (1) in the kind and (2) in the arrangement of the bundles. The bundles are, with few exceptions, of the concentric type, with the xylem in the centre, and they are arranged in one or more circles, with frequently a tangential, but never a radial, elongation. There may or may not be extra bundles and masses of sclerenchyma-fibres enclosed by the primary circle of bundles.

Such stems possess no cambium zone, and increase in thickness is therefore limited. A fern stem forty years old is no larger near its base than near its apex.

II. THE CLUB-MOSS TYPE.—Let cross-sections now be made of the common Club Moss, Lycopodium obscurum, and let one of them be treated with the phloroglucin reagent and another with chloral-hydrate iodine. The former will enable one to distinguish more clearly the xylem elements of the central cylinder, and the latter will better define the phloem elements.

Under a low magnifying power the section will appear as shown in Figure 2 (Pl. LXXXI.). *a* is the epidermis, consisting of a single layer of thickish-walled, cutinized, and often somewhat lignified cells; *b* is an area of thin-walled cells belonging to the exterior cortex, but the larger portion of the cortex is composed of excessively thick-walled cells or fibres (sclerenchyma-fibres). The central cylinder is here sharply marked off from the cortex by an area of thin-walled tissues, the outer of which layer of tissues probably represents an endodermis, though it is not very different in appearance from the rest of the tissues in this area. In the centre is another area composed of plates of xylem with scalariform tracheids separated from each other by plates of phloem.

The bundle would best be regarded, perhaps, as a radial bundle —in this particular case a fourteen-rayed one; but it might be re-

garded differently: each plate of xylem with the adjacent plates of phloem might be looked upon as constituting an incomplete concentric bundle like that in ferns. Thus the central cylinder would be composed of a group of imperfectly-formed concentric bundles enclosed by a common endodermis. In the stems of the Selaginellæ, related to the Lycopodii, there are usually two or more separate concentric bundles arranged side by side. The relationship is thus seen between the concentric and the radial bundle.

The club-moss type of stem, then, is one in which the central cylinder is occupied either by a single radial bundle or by two or more concentric bundles arranged side by side.

III. THE MONOCOTYL TYPE.—For the study of the monocotyl type of stem let transverse sections be made of the stem of the common Maize. A section stained by means of the anilin-chloride reagent will serve the purpose well. Under a very low magnifying power the stem presents the appearance shown in Figure 1 (Pl. LXXXII.). On one side of the stem is a notch, *a*, into which fitted the axillary bud borne on the node below. At the exterior of the section is the epidermis, composed, as usual, of a single stratum of cells. Interior to this is the cortex, composed, in the present instance, of only a few layers of thin-walled cells, and not separated from the central cylinder by a sheath, as is sometimes the case in this type of stem. The central cylinder is composed of parenchymatous ground tissues through which very numerous bundles are scattered. These bundles are smaller and closer together next the outside, where sometimes two or more partially coalesce. The bundles are all of the closed collateral type, and, as is usual in this kind of stem, the phloem faces exteriorly and the xylem faces toward the centre of the stem. The xylem portion of each bundle usually contains about two large ducts toward its outer face, next the phloem, and several smaller ones toward its inner face, where also there is usually to be found an irregular intercellular space of considerable size. The bundle is ensheathed by thick-walled fibres, most abundant and thickest walled at the outer and inner ends of the bundle. Those fibres at the outer or phloem end may be called bast-fibres; those at the inner or xylem end, wood-cells.

The closed collateral bundle is commonest in the stems of mono-

cotyls, though, as has been seen, the concentric bundle with a central phloem sometimes occurs.

The arrangement of bundles is also usually similar to that in Maize, but sometimes there are deviations more or less conspicuous. In most of the other grasses, for example, bundles are wanting at the centre of the stem, and the latter at maturity becomes hollow by the rupture of the parenchymatous cells. In the stems of Dracænas and in some other woody Liliaceæ there is a kind of cambium area in the boundary region between the central cylinder and the cortex in which new parenchyma and new bundles are formed, so that such stems increase in diameter from year to year as do those of dicotyls. But the bundles themselves in kind and arrangement are similar to those in the stems of other monocotyls. (See *College Botany*, pp. 187, 188.) In a few monocotyls also, as in the Yams, the stem structure closely approaches that of dicotyls.

To understand the distribution of the bundles in the monocotyl stem their course lengthwise of the stem must be traced. It must be understood that the bundles of the stem are continuous with those in the leaves, and that if the course of the bundles be traced from the leaves into the stem, it will be found that some of the bundles, after passing through the cortex into the central cylinder, turn immediately downward, while others do not bend downward until they have passed farther toward the centre of the stem. It thus happens that the downward course of some bundles is near the outside of the central cylinder, of others a little farther interior, and of still others near the centre. The distribution of the bundles already seen in cross-section is thus easily accounted for.

The downward course of the bundles is, however, not usually quite parallel to the surface of the stem, but the bundles incline a little outward until they finally terminate either in the roots or in the surface of the central cylinder. During this downward course they become smaller in size by the loss of some of their elements, until at their termination they may be quite depauperate. These facts account for the smaller size and the more crowded condition of the bundles toward the periphery of the central cylinder.

IV. The Dicotyl Type.—The stem of Menispermum Canadense is taken to illustrate one of the simplest forms of the dicotyl type of stem structure. Cross-sections should be made both from

old and from young portions of the stem—a series, for example, from a stem less than a year old, another from one about two years old, and a third from a still older stem. One set of sections may be treated with the anilin-chloride reagent, and another with the chloral-hydrate iodine solution.

Let sections of the youngest portion of the stem first be examined. Here three regions are distinguished: the epidermal, the cortical, and the central-cylinder region.

Beneath the one-layered epidermis, which in this plant persists for a long time and ultimately forms a very thick cuticle at its surface, is the thickish cortex, composed almost wholly of parenchyma, constituting the middle or green layer of the bark (mesophlœum). In the central cylinder lie the open collateral bundles, arranged radially about a central parenchyma—the pith or medulla—like the spokes of a wheel about its hub. Each bundle is separated laterally from the next by a plate of thin-walled parenchyma constituting a medullary ray. The xylem of each bundle faces the pith, the phloem faces the cortex, and the xylem is composed chiefly of large ducts and much smaller wood-cells, while the phloem forms a smaller mass and is made up chiefly of sieve- and companion-cells on its inner side and of a crescent-shaped mass of bast-fibres on its outer side.

Between phloem and xylem is meristem, which has the usual characteristics of this tissue. Because it is a part of the bundle it is called the "fascicular cambium." The meristem is, however, continued across the medullary ray from one bundle to the next, and thus forms a zone that separates the central cylinder into two portions: an inner portion, which includes the xylem part of all the bundles, the pith, and the inner portion of the medullary rays, and which is often called the woody cylinder; and an outer portion, which includes the phloem masses and the intervening outer ends of the medullary rays, and which together constitute the inner or bast layer of the bark (endophlœum).

Examining now one of the next older series of sections, it is found that the stem has considerably increased in diameter and that the bundles are measurably longer in a radial direction. Moreover, the xylem part of the bundles has increased in length proportionally much more rapidly than the phloem portions. The cells of the phloem may, however, easily be ascertained to have

increased considerably in number. The older sieve-tissues have, in fact, by the formation of others interior to them, been crowded up together against the unyielding bast-fibres until the cells appear collapsed.

If the section is from a stem two years old, two evident rings (rings of growth) will be seen in the wood; if the stem is three years old, three rings will be seen, and so on. In a stem three years old or more, bundles may often be seen which are divided into two at their outer extremity, each branch of the bundle being separated from the other by a short medullary ray. Such old stems may have the epidermis ruptured in places by the formation of cork-cells underneath.

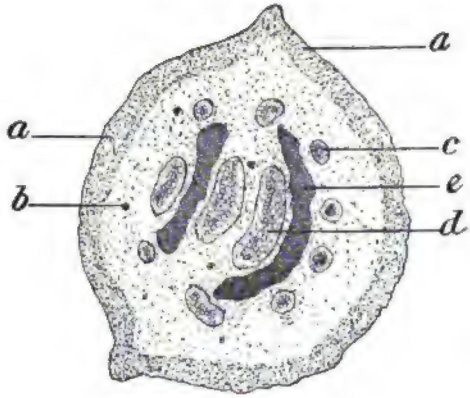
In some respects the stem of Menispermum differs from the stems of most other dicotyls, but in nearly all dicotyls and gymnosperms the bundles are of the open collateral type, arranged radially about a central pith and separated laterally from each other by medullary rays.

Most woody dicotyls differ from Menispermum in having narrow, lignified medullary rays which are also much shorter both in a radial and in a longitudinal direction. The first-formed bundles, usually few in number, divide repeatedly at the outer extremities, so that the medullary rays become increasingly numerous as the stem grows older.

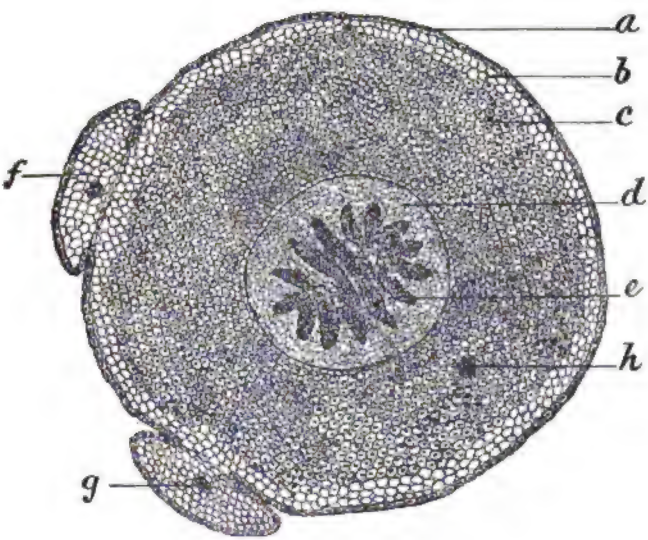
The course of the bundles in a dicotyl stem is well shown on p. 189 of *College Botany* (Figure 450), to which the student is referred.

In gymnosperms the arrangement of the bundles is similar to that in dicotyls, though the stems of the one may readily be distinguished from those of the other by the structure of their woody tissues, as explained in Exercise XI.

So far as the apex of the stem is concerned, in structure and in mode of growth it differs little from the root save in the absence of a cap. The growing-point is at the apex instead of just back of it, and in the club-mosses and phanerogams the growth takes place from a cluster of cells, while in the Equisetæ and ferns it takes place from a single cell, as in the roots of the same plants.



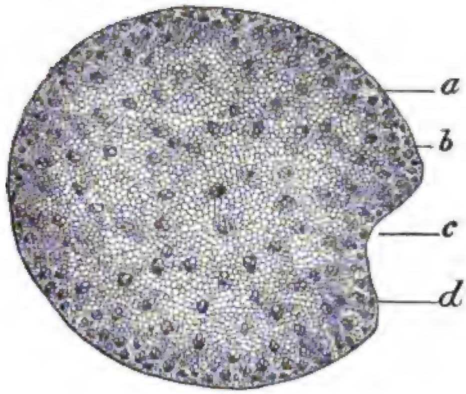
1



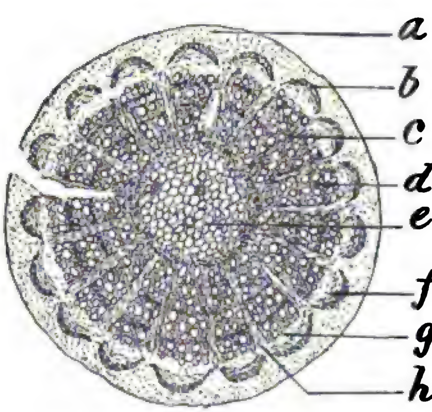
2

PLATE LXXXI., FIG. 1.—Transverse Section of Rhizome of Pteris aquilina (magnified about 7 diameters): *a*, *a*, hypoderma; *b*, small cluster of sclerenchyma-fibres in cortex; *c*, one of the circle of concentric bundles; *d*, one of the two interior large bundles; *e*, one of the two large brown masses of sclerenchyma-fibres.

FIG. 2.—Transverse Section of Stem of Lycopodium obscurum (magnified 30 diameters): *a*, epidermis; *b*, thin-walled cells of cortex beneath epidermis; *c*, sclerenchyma-fibres constituting the principal portion of the cortex; *d*, soft tissue (pericambium) in outer portion of central radial bundle; *e*, one of the xylem-rays; *f*, a leaf-base; *g*, vasal bundle in another leaf-base; *h*, a vasal bundle passing off to supply a leaf.



1



2

PLATE LXXXII., FIG. 1.—Transverse Section of Stem of Maize (magnified about 4 diameters): *a*, epidermis; *b*, thin cortex; *c*, indentation caused by a bud formed on internode below; *d*, one of the small bundles among the crowded ones at the outside of the central cylinder.

FIG. 2.—Transverse Section of Stem of Menispermum Canadense in the third year of its growth (magnified 8 diameters): *a*, cortex; *b*, crescent-shaped mass of bast-fibres; *c*, medullary ray; *d*, xylem of a bundle; *e*, pith; *f*, soft tissues of phloem; *g*, fascicular cambium; *h*, interfascicular cambium.

EXERCISE XXVI.

STUDY OF LEAF STRUCTURE.

LEAVES, so far as their internal structure is concerned, are of two principal types, the *bifacial* and the *centric*. These types differ chiefly in the arrangement of the chlorophyll-bearing parenchyma. In the bifacial type the parenchyma consists of two quite different layers facing the upper and lower surfaces respectively. The layer facing the upper surface has its cells compactly arranged and usually elongated in a direction perpendicular to the epidermis, forming what is called *palisade* parenchyma; the layer facing the lower surface has its cells loosely arranged and usually little if at all lengthened perpendicularly to the epidermis. In leaves of this kind the blade is always flattened, and habitually presents the deeper green surface, next which lies the palisade layer, upward or toward the stronger light. This surface usually has few or no stomata, while on the other surface they are numerous.

In the centric type of leaf there is but little structural difference between the parenchyma-layers facing the two surfaces, and seldom is anything resembling a palisade tissue developed next either surface, although, as a rule, the parenchyma is more spongy in the interior, is larger-celled, and contains less chlorophyll than the parenchyma adjacent to the surfaces. Terete, acicular, and succulent leaves usually belong to this class, but it may include flattened and even membranous forms. In this case, however, the two surfaces are nearly equally exposed to the light, and both possess stomata.

The following plants afford a good variety for study: *Bifacial leaves:* the Male Fern (Aspidium Filix-mas, *Swartz*), the Sago Palm (Cycas revoluta, *Willd.*), the Begonia (Begonia discolor, *H. K.*), the Eucalyptus (Eucalyptus globulus, *Lab.*), the Rue (Ruta graveolens, *Willd.*), the Oleander (Nerium Oleander, *L.*),

the Rubber Tree (Ficus elastica, *Roxb.*), the Nettle (Urtica dioica, *L*), the Beech (Fagus ferruginea, *Ait.*).

Centric leaves: the Austrian Pine (Pinus Laricio, *Poir.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Wheat (Triticum vulgare, *Villars*), the Adam's Needle (Yucca filamentosa, *L.*), the Sweet Flag (Acorus Calamus, *L.*), the Hyacinth (Hyacinthus orientalis, *Willd.*), and the Daffodil (Narcissus Pseudo-narcissus, *L.*).

I. BIFACIAL LEAVES.—(1) Let the leaf of Ficus elastica first be studied. The leaf being leathery and firm in texture, sections of it may readily be made, without hardening in alcohol, by placing portions of it between flat pieces of pith and cutting through both pith and leaf. Specimens which have laid for some time in alcohol are to be preferred, because they have been rendered more transparent by the removal of the chlorophyll. The sections would better be made transversely, across the direction of the lateral veins.

A section may be mounted in a drop of carbolic-acid solution or in one of chloral hydrate, or, if the leaf had previously been treated with alcohol, in glycerin, and then be examined first with a low and afterward with a high power.

It will be observed that the epidermis of both upper and lower surfaces is composed of three tiers of transparent cells; but the upper epidermis is thicker than the lower, by reason of the larger size of the cells in its two inner layers. A two- or more layered epidermis is not uncommon among the leathery evergreen leaves of warm climates. Probably the thickness of the epidermis both tempers the intensity of the sun's rays and retards evaporation from the leaf.

At intervals in the inner tier of epidermal cells on the upper side, and more rarely on the lower, are very large cells containing each a botryoidal mass attached by a stalk to the cell-wall as shown at *b*, Figure 1 (Pl. LXXXIII.). This mass is called a *cystolith.* Bodies of this kind are not common in plants, rarely occurring outside the orders Urticaceæ, Acanthaceæ, and a few species of the Cucurbitaceæ.

Interior to the upper epidermis are seen the palisade cells arranged in two tiers. In both tiers the cells are lengthened in a direction perpendicular to the epidermis, but the cells of the ex-

terior tier are considerably longer. The cells, it will be observed, are heavily charged with chlorophyll bodies.

The middle portion of the leaf is occupied chiefly by a very loosely arranged chlorophyll-bearing parenchyma consisting of cells which are ellipsoidal in form, or more often irregular or even branching, the cells being arranged without apparent order. This tissue, next the lower epidermis, passes into a parenchyma which has its cells somewhat compactly arranged, but still not forming a palisade tissue. All this parenchymatous portion included between the palisade tissue and the lower epidermis is called *spongy parenchyma.* Its chlorophyll bodies are not nearly so numerous as in the palisade tissue; this fact, together with that of the less compact arrangement of its cells, accounts for the much lighter green of the dorsal surface of the leaf.

In this leaf the lower epidermis is the only one in which are found stomata. In a fortunate section which cuts one of the stomata transversely near its middle the appearance will be as at *f* in the drawing. The guard-cells are so shaped as to form a kind of ante-chamber (*f*) which opens by a narrow passage into a large air-chamber (*g*) which is in communication with the intercellular spaces throughout the leaf.

An effort may now be made to determine the chemical nature of the cystolith. For this purpose a fresh section may be mounted in a drop of water, and after focusing upon a cystolith a drop of acetic acid may be placed at the edge of the cover and be allowed to run under. As the acid comes into contact with the cystolith effervescence occurs and bubbles of gas accumulate in the cell, indicating the presence of calcium carbonate. After effervescence ceases the cystolith appears to the eye very much as before, except that it is more transparent.

Removing now the cover-glass, washing away the acetic acid with clean water, afterward soaking up the latter with blotting paper, and applying two or three drops of the zinc-chloriodide iodine, the characteristic blue color due to cellulose is developed in the skeleton of the cystolith that remains. Cystoliths usually, as in the present instance, consist of a cellulose skeleton, formed by an infolding or ingrowth of the cell-wall, encrusted by calcium carbonate. The latter, however, not merely forms at the surface of the skeleton, but penetrates its mass.

Attention is also directed to the cross-sections of the veins. These are seen to consist chiefly of a collateral vasal bundle in which the phloem faces toward the lower or dorsal side of the leaf, and the xylem toward the upper or ventral side. This is always the case in leaves, so that in those that have been separated from the plant or in those that have become twisted on their petioles the true dorsal or ventral side may be determined by an examination of the bundle.

A cross-section made through the midrib would be instructive as showing the much greater prominence of the rib on the dorsal surface of the leaf, and also as showing a vasal bundle with its parts much better developed than in the bundle shown in Figure 1 (Pl. LXXXIII.). In distinguishing between different medicinal leaves the bundle or bundles of the midrib may usually be expected to afford important diagnostic characters, as the structure and arrangement of the bundles often differ quite widely in leaves of different species.

(2) A bifacial leaf whose structure differs considerably from that of the leaf just studied is the pinnately-compound leaf of Cycas revoluta. Here the texture is also coriaceous and firm, and sections may be made as before; but in order to comprehend the structure fully it will be necessary to make sections in several different directions.

First let a transverse section be made perpendicularly to the direction of the midrib. It would be wise to cut several of these sections, so that one may be found sufficiently thin to reveal the structure clearly. The thinnest sections are then transferred to a slide and treated with the phloroglucin reagent. On focusing upon one of the sections with the low power an appearance will be presented which is illustrated in Figure 2 (Pl. LXXXIII.). The leaflets are much the thickest at the middle, along the mid-vein, which, as usual, is most prominent on the lower side, and, since the leaflets are revolute, the thinner portions on either side of the mid-vein appear strongly curved when viewed in section. The upper epidermis is thick-walled and single-layered. The exterior portion, because composed of cutin, does not stain with the phloroglucin, while the remainder of the wall does stain quite strongly, especially in old leaves, indicating lignification. The epidermis is supported by a layer (or at the midrib by two layers)

of thick-walled cells constituting a hypoderma. Immediately interior to the hypodermal tissue is a single layer of much elongated palisade cells. The second layer in this case is but slightly developed. This is followed still farther interior by a spongy parenchyma composed of thickish-walled, somewhat lignified, and strongly pitted parenchyma. The cells in this region, nearly midway between the two surfaces of the leaf, contain little if any chlorophyll, while those near the palisade tissue on the one hand and the lower epidermis on the other contain chlorophyll, though in less quantity than do the palisade cells. The cells are all regular in form, and are mostly much lengthened in a direction perpendicular to the midrib and parallel to the epidermis.

Focusing up and down on this tissue, it is found that, like other spongy parenchyma, it is very loosely arranged, but here the spaces are larger and more regular than in the leaf of Ficus elastica.

Next the lower epidermis is an interrupted layer, or in places two layers, of chlorophyll-bearing cells which are slightly elongated in the other direction—namely, perpendicularly to the epidermis—thus constituting a very imperfectly developed palisade tissue. The interruptions in this layer are the places where the air-chambers occur over the stomata, which are very numerous between the midrib and the margin on the lower surface, but which are not found elsewhere in the leaf.

Examining the same sections with the high power, it will be found that the stomata located in the single-layered epidermis present some striking peculiarities. Referring to Plate LXXXIV., the air-chamber over one of the stomata is shown at *f*, and an exterior opening at *h*. This, however, is not the stoma proper, but is rather the opening into a vestibular cavity which leads to the stoma above. A favorable section shows the guard-cells as indicated in the drawing. Where they meet, as at *i*, there is an excessive thickening which is also strongly lignified, while the rest of the wall remains relatively thin, and that portion which faces the vestibular cavity is wholly unlignified.

The cells bounding the vestibular cavity are long cells, pointed at their exterior ends and curved, and so placed as to form a dome-shaped prominence in the lower epidermis, the dome being perforated at the top by a rounded aperture. The arrangement of these cells will be understood better by reference to Figure 1

(Pl. LXXXVI.), in which *b* represents a vestibular cell, and *a* the vestibular aperture. The section from which the drawing was made was prepared by shaving off a portion of the epidermis, cutting just beneath it parallel to the surface.

In Figure 2 (Pl. LXXXVI.) the section passed through the epidermis itself, parallel to and near the surface, cutting off the dome-cells near their bases and exposing the stoma. The latter presents no especial peculiarities except the strong bracing at the ends of the guard-cells, preventing all movement in the direction of the length of the stoma. It will readily be seen, by comparing this with the sectional view in Figure 3, that any movement of expansion must cause the guard-cells to bow out in the middle, thus enlarging the aperture between them.

A section of the leaflet made parallel to the midrib and perpendicular to its upper and lower surfaces is also instructive in many ways. Such a section is shown in Figure 1 (Pl. LXXXV.). The hypodermal cells are here seen to be much elongated and even fibrous in their character; and that the spongy parenchyma is composed of plates of elongated cells with large intercellular spaces between the plates is now clearly seen by comparison with Figure 3.

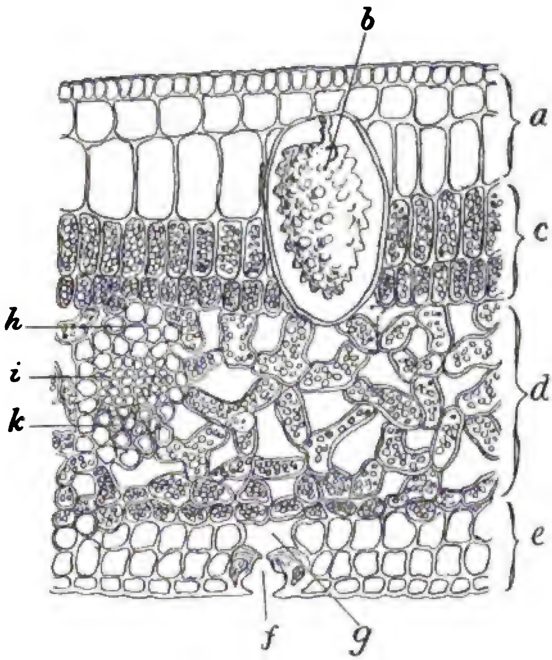
A quite unusual thing in leaf structure is the fact that in the leaf of Cycas so large a proportion of the cells of the mature leaf are lignified and pitted. This is true even of the epidermal cells (except, of course, the cuticle) and of the cells of the mesophyll (except the palisade tissue); but even this tissue possesses strongly-thickened vertical bands in the walls of its cells, many of which bands are lignified. A section cut across the longer diameter of the palisade cells shows this fact beautifully. Figure 2 (Pl. LXXXV.) represents a few palisade cells as seen in such a section: *a* is an intercellular space; *b*, a lignified thickening; *c*, an unthickened portion of the cell-wall. The portion from which the illustration was drawn consisted of cells more compactly arranged than most of the cells of this tissue, but even in the more loosely arranged cells the walls possess thickenings similar to those in the drawing.

II. Centric Leaves.—Let the centric type of leaf structure be exemplified in cross-sections of the leaf of Pinus Laricio, not uncommonly cultivated in this country under the name of "Austrian Pine."

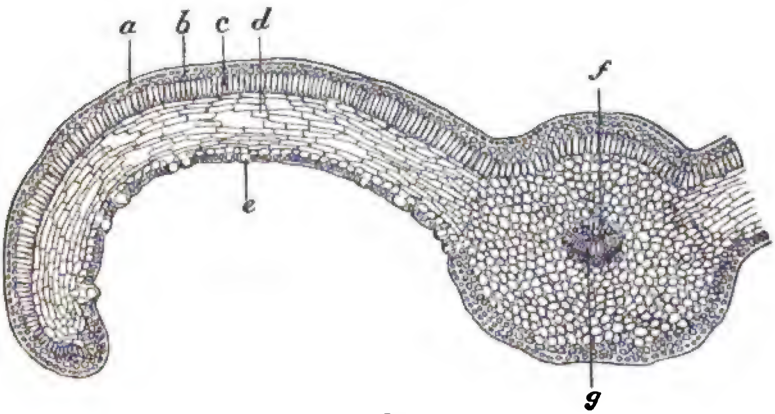
Good sections are easily made, either of fresh or of alcoholic material, by cutting the leaves between pieces of pith. In order to understand the structure well, it is advisable to clear the sections by means of carbolic acid, or, better, by treating them with Labarraque's solution until colorless, washing them thoroughly and double-staining—say with iodine-green and ammonia carmine—and, after anhydrating, mounting them in balsam.

The sections are nearly straight on one edge (the ventral, as will be shown by studying the bundles) and strongly curved, nearly semicircular, on the other. The excessively thick-walled and one-layered epidermis is punctured at frequent intervals, as well on the ventral as on the dorsal surface, by stomata. Beneath the epidermis is a hypoderma composed of two or three layers of thick-walled fibrous cells interrupted only where the stomata occur. Interior to this hypoderma, on both sides of the leaf, is a peculiar, thin-walled, chlorophyll-bearing parenchyma. The walls of its cells are thrown into numerous folds which project into the cell-lumen. Arranged at nearly equal intervals in this parenchyma, around the axial portion of the leaf, are from four to six secretion-reservoirs in which the circle of secreting cells is ensheathed by one of thick-walled cells.

The axial portion of the leaf is separated from the rest by a distinct sheath of rather large and not very thick-walled cells, interior to which, and surrounding a pair of collateral vasal bundles, are several layers of parenchyma-cells possessing bordered pits similar to those of the tracheids so characteristic of the woody portions of gymnosperms.



1



2

PLATE LXXXIII., FIG. 1.—Small portion of Cross-section of Leaf of Ficus elastica, illustrating a bifacial leaf (magnification, 150 diameters); *a*, upper epidermis; *b*, cystolith in an extra large epidermal cell; *c*, palisade parenchyma; *d*, spongy parenchyma; *e*, lower or dorsal epidermis; *f*, stoma; *g*, air-chamber above stoma; *h*, xylem of a small bundle; *i*, soft bast of the bundle; *k*, hard bast or bast-fibres.

FIG. 2.—Portion of Cross-section of Leaf of Cycas revoluta (magnified 40 diameters): *a*, epidermis; *b*, hypoderma; *c*, palisade tissue; *d*, spongy parenchyma; *e*, stoma; *f*, xylem of bundle constituting the midvein; *g*, phloem of the same.

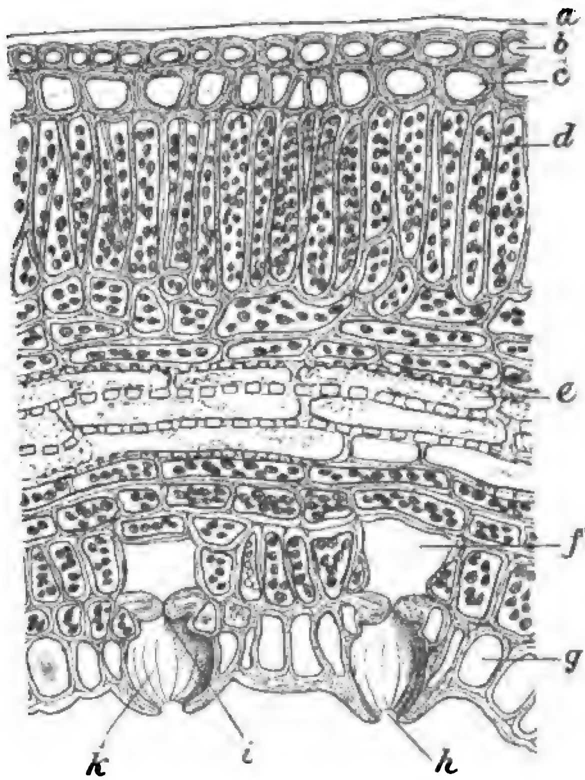
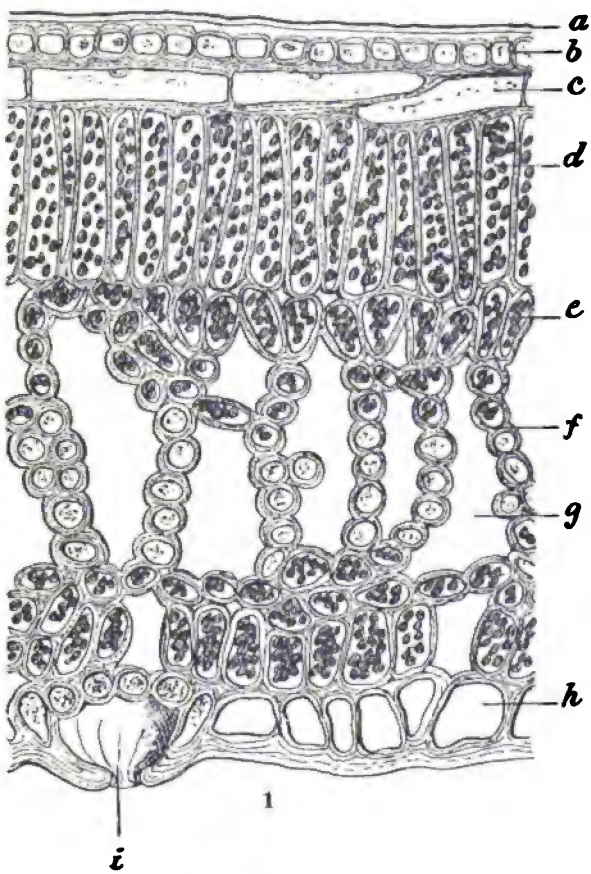


PLATE LXXXIV.—Small portion of the Cross-section of the Leaflet of Cycas revoluta (**magnified** 210 diameters): *a*, cuticle; *b*, epidermal cells; *c*. hypoderma; *d*, palisade **parenchyma**; *e*, pitted cells in middle portion of spongy parenchyma, which contain few if any chloroplasts; *f*, air-chamber above stoma; *g*, ordinary epidermal cell of lower epidermis; *h*, opening into vestibular cavity of stoma; *i*, a stoma; *k*, vestibular cavity.



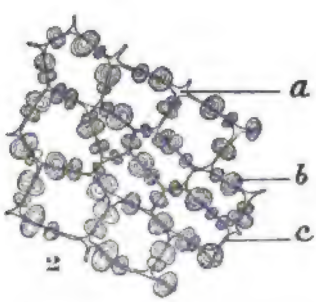
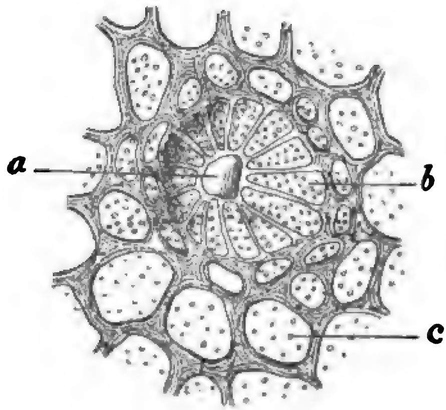
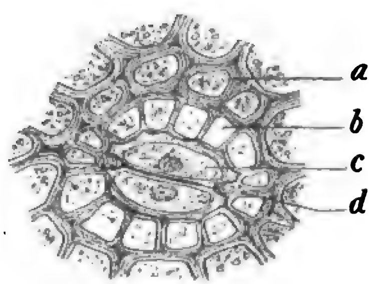


PLATE LXXXV., FIG. 1.—Small portion of section of Leaflet of Cycas revoluta, made vertically through the leaflet parallel to the midrib (magnified 210 diameters): *a*, cuticle; *b*, epidermis; *c*, hypoderma; *d*, palisade parenchyma; *e*, imperfectly developed second tier of palisade cells; *f*, spongy parenchyma; *g*, large air-space between plates of spongy parenchyma; *h*, ordinary epidermal cell of lower epidermis; *i*, vestibule of stoma.

FIG. 2.—A few Palisade Cells of Cycas leaf cut perpendicular to their longest diameter: *a*, intercellular space; *b*, lignified thickening; *c*, ordinary thin portion of wall. (Magnification, 330 diameters.)



1



2

PLATE LXXXVI., Fig. 1.—View of small portion of Lower Epidermis of Cycas leaf as seen from below (magnified 330 diameters) : *b*, one of the cells forming the dome-shaped vestibule of the stoma (the outer ends of the cells are strongly cutinized and their walls are pitted) ; *a*, vestibular opening ; *c*, ordinary epidermal cell (its walls are also pitted).

Fig. 2.—Small portion of Epidermis from lower side of Cycas leaf, cut parallel to and near the surface, opening the vestibular cavity so as to show the stoma (magnification, 330 diameters) : *a*, ordinary epidermal cell : *b*, base of one of the vestibular cells ; *c*, one of the guard-cells ; *d*, strong lignified thickening at the end of the stoma.

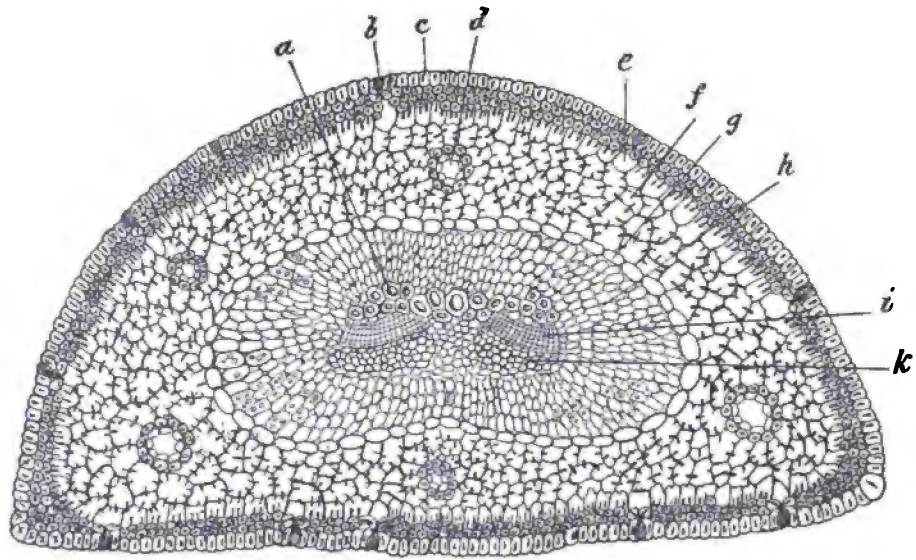


PLATE LXXXVII.—Transverse Section of Leaf of Pinus Laricio, illustrating the structure of a centric leaf (magnified about 65 diameters). The section had been cleared of the cell-contents. *a*, bast-fibre; *b*, stoma; *c*, epidermal cell; *d*, secretion-reservoir; *e*, air-chamber into which a stoma opens; *f*, folded parenchyma, the parenchyma which contains the chlorophyll; *g*, bundle-sheath; *h*, pitted parenchyma surrounding bundles; *i*, soft bast of one of the two bundles; *k*, xylem of one of the bundles.

INDEX.

Standard Medical and Surgical Works

PUBLISHED BY

W. B. SAUNDERS, 925 Walnut Street, Philadelphia, Pa.

MR. SAUNDERS, in presenting to the profession the following list of his publications, begs to state that the aim has been to make them worthy of the confidence of medical book-buyers by the high standard of *authorship* and by the excellence of *typography, paper, printing,* and *binding.*

The works indicated thus (*) are sold by SUBSCRIPTION (*not by booksellers*), usually through travelling solicitors, but they can be obtained *direct* from the office of publication (charges of shipment prepaid) by remitting the quoted prices. Full *descriptive cirulars* of such works will be sent to any address upon application.

All the other BOOKS advertised in this catalogue are commonly for sale by *booksellers* in all parts of the United States; but any book will be sent by the publisher to any address (post-paid) on receipt of the price herein given.

(*For Announcement of Forthcoming Publications see next page.*)

Announcement of Forthcoming Publications.

AN AMERICAN TEXT-BOOK OF OBSTETRICS. By American Teachers. (See page 8)

AN AMERICAN TEXT-BOOK OF PHYSIOLOGY. By American Teachers. (See page 8.)

AN AMERICAN TEXT-BOOK OF APPLIED THERAPEUTICS. By American Teachers.

AN AMERICAN TEXT-BOOK OF NURSING. By American Teachers.

SURGICAL PATHOLOGY AND THERAPEUTICS. By J. Collins Warren, M. D., Professor of Surgery, Harvard Medical School, etc. (See page 10.)

A SYLLABUS OF GYNÆCOLOGY, arranged in conformity with The American Text-Book of Gynecology. By J. W. Long, M. D., Professor of Diseases of Women and Children, Medical College of Virginia, etc. (See page 9.)

TEMPERATURE CHART. Prepared by D. T. Lainé, M. D. (See page 9.)

LABORATORY EXERCISES IN BOTANY. By Edson S. Bastin, M. A., Professor of Materia Medica and Botany in the Philadelphia College of Pharmacy. (See page 18.)

A GUIDE TO THE BACTERIOLOGICAL LABORATORY. By Langdon Frothingham, M. D (See page 14.)

SAUNDERS' NEW AID SERIES OF MANUALS.

New volumes in active preparation. See pages 11, 12.

For Sale by Subscription.

AN AMERICAN TEXT-BOOK OF THE DISEASES OF CHILDREN. By American Teachers. Edited by LOUIS STARR, M. D., assisted by THOMPSON S. WESTCOTT, M. D. In one handsome royal-8vo volume of 1190 pages, profusely illustrated with wood-cuts, half-tone and colored plates. Net Prices: Cloth, $7.00; Sheep, $8.00; Half Russia, $9.00.

The plan of this work embraces a series of original articles written by some sixty well-known pædiatrists, representing collectively the teachings of the most prominent medical schools and colleges of America. The work is intended to be a PRACTICAL book, suitable for constant and handy reference by the practitioner and the advanced student.

One decided innovation is the large number of authors, nearly every article being contributed by a specialist in the line on which he writes. This, while entailing considerable labor upon the editors, has resulted in the publication of a work THOROUGHLY NEW AND ABREAST OF THE TIMES.

Especial attention has been given to the latest accepted teachings upon the etiology, symptoms, pathology, diagnosis, and treatment of the disorders of children, with the introduction of many special formulæ and therapeutic procedures.

Special chapters embrace at unusual length the Diseases of the Eye, Ear, Nose and Throat, and the Skin; while the introductory chapters cover fully the important subjects of Diet, Hygiene, Exercise, Bathing, and the Chemistry of Food. Tracheotomy, Intubation, Circumcision, and such minor surgical procedures coming within the province of the medical practitioner are carefully considered.

CONTRIBUTORS:

Dr. S. S. Adams, Washington.
John Ashhurst, Jr., Philadelphia.
A. D. Blackader, Montreal, Canada.
Dillon Brown, New York.
Edward M. Buckingham, Boston.
Charles W. Burr, Philadelphia.
W. E. Casselberry, Chicago.
Henry Dwight Chapin, New York.
W. S. Christopher, Chicago.
Archibald Church, Chicago.
Floyd M. Crandall, New York.
Andrew F. Currier, New York.
Roland G. Curtin, Philadelphia
J. M. DaCosta, Philadelphia.
I. N. Danforth, Chicago.
Edward P. Davis, Philadelphia.
John B. Deaver, Philadelphia.
G. E. de Schweinitz, Philadelphia.
John Dorning, New York.
Charles Warrington Earle, Chicago.
Wm. A. Edwards, San Diego, Cal.
F. Forchheimer, Cincinnati.
J. Henry Fruitnight, New York.
Landon Carter Gray, New York.
J. P. Crozer Griffith, Philadelphia.
W. A. Hardaway, St. Louis.
M. P Hatfield, Chicago.
Barton Cooke Hirst, Philadelphia.
H. Illoway, Cincinnati.
Henry Jackson, Boston.
Charles G. Jennings, Detroit.
Henry Koplik, New York.

Dr. Thomas S. Latimer, Baltimore.
Albert R. Leeds, Hoboken, N. J.
J. Hendrie Lloyd, Philadelphia.
George Roe Lockwood, New York.
Henry M. Lyman, Chicago.
Francis T. Miles, Baltimore.
Charles K. Mills, Philadelphia.
John H. Musser, Philadelphia.
Thomas R. Neilson, Philadelphia.
W. P. Northrup, New York.
William Osler, Baltimore.
Frederick A. Packard, Philadelphia.
William Pepper, Philadelphia.
Frederick Peterson, New York.
W. T. Plant, Syracuse, New York.
William M. Powell, Atlantic City.
B. Alexander Randall, Philadelphia.
Edward O. Shakespeare, Philadelphia.
F. C. Shattuck, Boston.
J. Lewis Smith, New York.
Louis Starr, Philadelphia.
M. Allen Starr, New York.
J. Madison Taylor, Philadelphia.
Charles W. Townsend, Boston.
James Tyson, Philadelphia.
W. S. Thayer, Baltimore.
Victor C. Vaughan, Ann Arbor, Mich.
Thompson S. Westcott, Philadelphia.
Henry R. Wharton, Philadelphia.
J. William White, Philadelphia.
J. C. Wilson, Philadelphia.

For Sale by Subscription.

DISEASES OF THE EYE. A Handbook of Ophthalmic Practice. By G. E. DE SCHWEINITZ, M. D., Professor of Diseases of the Eye, Philadelphia Polyclinic; Professor of Clinical Ophthalmology, Jefferson Medical College, Philadelphia, etc. Forming a handsome royal-octavo volume of more than 600 pages, with over 200 fine wood-cuts, many of which are original, and 2 chromo-lithographic plates. Prices: Cloth, $4.00 net; Sheep, $5.00 net; Half Russia, $5.50 net.

The object of this work is to present to the student and practitioner who is beginning work in the fields of ophthalmology a plain description of the optical defects and diseases of the eye. To this end special attention has been paid to the clinical side of the question; and the method of examination, the symptomatology leading to a diagnosis, and the treatment of the various ocular defects have been brought into special prominence. The general plan of the book is eminently practical. Attention is called to the large number of illustrations (nearly one-third of which are new), which will materially facilitate the thorough understanding of the subject.

"For the student and practitioner it is the best single volume at present published."—*Medical News*, Philadelphia.

"A most complete and sterling presentation of the present status of modern knowledge concerning diseases of the eye."—*Medical Age.*

"Pre-eminently a book for those wishing a clear yet comprehensive and full knowledge of the fundamental truths which underlie and govern the practice of ophthalmology."—*Medical and Surgical Reporter.*

"At once comprehensive and thoroughly up to date."—*Hospital Gazette* (London).

PROFESSIONAL OPINIONS.

"A work that will meet the requirements not only of the specialist, but of the general practitioner in a rare degree. I am satisfied that unusual success awaits it."

WILLIAM PEPPER, M. D.,
Provost and Professor of Theory and Practice of Medicine and Clinical Medicine in the University of Pennsylvania.

"Contains in concise and reliable form the accepted views of Ophthalmic Science."

WILLIAM THOMSON, M. D.,
Professor of Ophthalmology, Jefferson Medical College, Philadelphia, Pa.

"Contains in the most attractive and easily understood form just the sort of knowledge which is necessary to the intelligent practice of general medicine and surgery."

J. WILLIAM WHITE, M. D.,
Professor of Clinical Surgery in the University of Pennsylvania.

"A very reliable guide to the study of eye diseases, presenting the latest facts and newest ideas."

SWAN M. BURNETT, M. D.,
Professor of Ophthalmology and Otology, Medical Department Univ. of Georgetown, Washington, D. C.

For Sale by Subscription.

MEDICAL DIAGNOSIS. By Dr. OSWALD VIERORDT, Professor of Medicine at the University of Heidelberg. Translated, with additions, from the Second Enlarged German Edition, with the author's permission, by FRANCIS H. STUART, A. M., M. D. Third and Revised Edition. In one handsome royal-octavo volume of 700 pages, 178 fine wood-cuts in text, many of which are in colors. Prices: Cloth, $4.00 net; Sheep, $5.00 net; Half Russia, $5.50 net.

In this work, as in no other hitherto published, are given full and accurate explanations of the phenomena observed at the bedside. It is distinctly a clinical work by a master teacher, characterized by thoroughness, fulness, and accuracy. It is a mine of information upon the points that are so often passed over without explanation. Especial attention has been given to the germ-theory as a factor in the origin of disease.

This valuable work is now published in German, English, Russian, and Italian. The issue of a third American edition within two years indicates the favor with which it has been received by the profession.

"Rarely is a book published with which a reviewer can find so little fault as with the volume before us. All the chapters are full, and leave little to be desired by the reader. Each particular item in the consideration of an organ or apparatus, which is necessary to determine a diagnosis of any disease of that organ, is mentioned; nothing seems forgotten. The chapters on diseases of the circulatory and digestive apparatus and nervous system are especially full and valuable. Notwithstanding a few minor errors in translating, which are of small importance to the accuracy of the rest of the volume, the reviewer would repeat that the book is one of the best—probably *the best*—which has fallen into his hands. An excellent and comprehensive index of nearly one hundred pages closes the volume."—*University Medical Magazine*, Philadelphia.

"Thorough and exact. . . . . The author has rendered no mean service to medicine in having prepared a work which proves as useful to the teacher as to the student and practitioner."—*The Lancet* (London).

PROFESSIONAL OPINIONS.

"One of the most valuable and useful works in medical literature."

ALEXANDER J. C. SKENE, M. D.,
Dean of the Long Island College Hospital, and Professor of the Medical and Surgical Diseases of Women.

"Indispensable to both 'students and practitioners.'"

F. MINOT, M. D.,
Hersey Professor of Theory and Practice of Medicine, Harvard University.

"It is very well arranged and very complete, and contains valuable features not usually found in the ordinary books."

J. H. MUSSER, M. D.,
Assistant Professor Clinical Medicine, University of Pennsylvania.

"One of the most valuable works now before the profession, both for study and reference."

N. S. DAVIS, M. D.,
Professor of Principles and Practice of Medicine and Clinical Medicine, Chicago Medical College.

For Sale by Subscription.

A NEW PRONOUNCING DICTIONARY OF MEDICINE, with Phonetic Pronunciation, Accentuation, Etymology, etc. By JOHN M. KEATING, M. D., LL.D., Fellow of the College of Physicians of Philadelphia; Vice-President of the American Pædiatric Society; Ex-President of the Association of Life Insurance Medical Directors; Editor "Cyclopædia of the Diseases of Children," etc.; and HENRY HAMILTON, author of "A New Translation of Virgil's Æneid into English Rhyme;" co-author of "Saunders' Medical Lexicon," etc.; with the Collaboration of J. CHALMERS DACOSTA, M. D., and FREDERICK A. PACKARD, M. D. With an Appendix containing important Tables of Bacilli, Micrococci, Leucomaïnes, Ptomaïnes, Drugs and Materials used in Antiseptic Surgery, Poisons and their Antidotes, Weights and Measures, Thermometric Scales, New Official and Unofficial Drugs, etc. Forming one very attractive volume of over 800 pages. Second Revised Edition. Prices: Cloth, $5.00 net; Sheep, $6.00 net; Half Russia, $6.50 net. With Denison's Patent Index for Ready Reference.

PROFESSIONAL OPINIONS.

"I am much pleased with Keating's Dictionary, and shall take pleasure in recommending it to my classes."

HENRY M. LYMAN, M. D.,
Professor of Principles and Practice of Medicine, Rush Medical College, Chicago, Ill.

"I am convinced that it will be a very valuable adjunct to my study-table, convenient in size and sufficiently full for ordinary use."

C. A. LINDSLEY, M. D.,
Professor of Theory and Practice of Medicine, Medical Dept. Yale University; Secretary Connecticut State Board of Health, New Haven, Conn.

"I will point out to my classes the many good features of this book as compared with others, which will, I am sure, make it very popular with students."

JOHN CRONYN, M. D., LL.D.,
Professor of Principles and Practice of Medicine and Clinical Medicine; President of the Faculty, Medical Dept. Niagara University, Buffalo, N. Y.

AUTOBIOGRAPHY OF SAMUEL D. GROSS, M. D., Emeritus Professor of Surgery in the Jefferson Medical College of Philadelphia, with Reminiscences of His Times and Contemporaries. Edited by his sons, SAMUEL W. GROSS, M. D., LL.D., late Professor of Principles of Surgery and of Clinical Surgery in the Jefferson Medical College, and A. HALLER GROSS, A. M., of the Philadelphia Bar. Preceded by a Memoir of Dr. Gross, by the late Austin Flint, M. D., LL.D. In two handsome volumes, each containing over 400 pages, demy 8vo, extra cloth, gilt tops, with fine Frontispiece engraved on steel. Price, $5.00 net.

This autobiography, which was continued by the late eminent surgeon until within three months of his death, contains a full and accurate history of his early struggles, trials, and subsequent successes, told in a singularly interesting and charming manner, and embraces short and graphic pen-portraits of many of the most distinguished men—surgeons, physicians, divines, lawyers, statesmen, scientists, etc.—with whom he was brought in contact in America and in Europe; the whole forming a retrospect of more than three-quarters of a century.

For Sale by Subscription.

AN AMERICAN TEXT-BOOK OF OBSTETRICS. By American Teachers. By Richard C. Norris, A. M., M. D.; James H. Etheridge, M. D.; Chauncey D. Palmer, M. D.; Howard A. Kelly, M. D.; Charles Jewett, M. D.; Henry J. Garrigues, M. D.; Barton Cooke Hirst, M. D.; Theophilus Parvin, M. D.; George A. Piersol, M. D.; Edward P. Davis, M. D.; Charles Warrington Earle, M. D.; Robert L. Dickinson, M. D.; Edward Reynolds, M. D.; Henry Schwarz, M. D.; and James C. Cameron, M. D. In one very handsome imperial-octavo volume, with a large number of original illustrations, including full-page plates, and uniform with "The American Text-Book of Gynecology." (In active preparation.)

Such an array of well-known teachers is a sufficient guarantee of the high character of the work, and it gives the assurance that this work will have the same measure of success awarded it as has attended the recent publication of its companion volume, "The American Text-Book of Gynecology." The illustrations will receive the most minute attention; the cuts interspersed throughout the text, and the full-page plates, which will reflect the highest attainments of the artist and engraver, will appeal at once to the eye as well as to the mind of the student and practitioner.

AN AMERICAN TEXT-BOOK OF PHYSIOLOGY. By American Teachers. Edited by WILLIAM H. HOWELL, PH. D., M. D., Professor of Physiology, Johns Hopkins University. With the collaboration of such eminent specialists as Henry P. Bowditch, M. D.; John G. Curtis, M. D.; Henry H. Donaldson, M. D.; Frederick S. Lee, M. D.; Warren P. Lombard, A. B., M. D.; Graham Lusk, PH. D.; Henry Sewall, M. D.; Edward T. Reichert, M. D.; Joseph W. Warren, M. D. In one imperial-octavo volume (with a large number of original illustrations), uniform with The American Text-Books of "Surgery," "Practice," "Gynecology," etc. (In preparation for early publication.)

This will be the most notable attempt yet made in this country to combine in one volume the entire subject of Human Physiology by well-known teachers who have given especial study to that part of the subject upon which they will write. The completed work will represent the present status of the science of Physiology, and in particular from the standpoint of the student of medicine and the medical practitioner. Illustrations largely drawn from original sources will be used freely throughout the text.

AN AMERICAN TEXT-BOOK OF APPLIED THERAPEUTICS. By American Teachers. (In preparation.)

AN AMERICAN TEXT-BOOK OF NURSING. By American Teachers. (In preparation.)

A SYLLABUS OF GYNÆCOLOGY, arranged in conformity with The American Text-Book of Gynecology. By J. W. Long, M. D., Professor of Diseases of Women and Children, Medical College of Virginia, etc. (Preparing.)

Based upon the teaching and methods laid down in the larger work, this will not only be useful as a supplementary volume, but to those who do not already possess the text-book it will also have an independent value as an aid to the practitioner in gynecological work, and to the student as a guide in the lecture-room, as the subject is presented in a manner at once systematic, clear, succinct, and practical.

TEMPERATURE CHART. Prepared by D. T. Laine, M. D. Size 8 x 13½ inches. Price, per pad of 25 charts, 50 cents.

A conveniently arranged chart for recording Temperature, with columns for daily amounts of Urinary and Fecal Excretions, Food, Remarks, etc. On the back of each chart is given in full the method of Brand in the treatment of Typhoid Fever.

THE NURSE'S DICTIONARY of Medical Terms and Nursing Treatment, containing Definitions of the Principal Medical and Nursing Terms, Abbreviations, and Physiological Names, and Descriptions of the Instruments, Drugs, Diseases, Accidents, Treatments, Operations, Foods, Appliances, etc. encountered in the ward or in the sick-room. Compiled for the use of nurses. By Honnor Morten, author of "How to Become a Nurse," "Sketches of Hospital Life," etc. Second and enlarged edition. 16mo, 140 pages. Price, Cloth, $1.00.

This little volume is intended for use merely as a small reference-book which can be consulted at the bedside or in the ward. It gives sufficient explanation to the nurse to enable her to comprehend a case until she has leisure to look up larger and fuller works on the subject.

"Should be at the disposal of every nurse."—*Birmingham Medical Review.*

"Maintains its reputation for brevity and simplicity."—*Hahnemannian Monthly.*

"Though ostensibly for professional nurses, contains in a compact form just such information as almost every intelligent man would like to have at hand in these days when the interest in all matters of sanitation and medicine has become so great."—*Medical Examiner.*

"A book which every progressive nurse must have."—*Medical World.*

"This little volume is almost indispensable in the training school and in the library of the nurse."—*New York Medical Times.*

SURGICAL PATHOLOGY AND THERAPEUTICS. By J. COLLINS WARREN, M. D., Professor of Surgery, Harvard Medical School, etc. In one very handsome octavo volume of over 800 pages, with 135 illustrations, 33 of which are chromo-lithographs, and all of which are drawn from original specimens. (Passing through the press.)

Covering as it does the entire field of Surgical Pathology and Surgical Therapeutics by an acknowledged authority, the publisher is confident that the work will rank as a standard authority on the subject of which it treats. Particular attention has been paid to Bacteriology and Surgical Bacteria from the standpoint of recent investigations, and the chromo-lithographic plates in their fidelity to nature and in scientific accuracy have hitherto been unapproached.

DISEASES OF WOMEN. By HENRY J. GARRIGUES, A. M., M. D., Professor of Obstetrics in the New York Post-Graduate Medical School and Hospital; Gynecologist to St. Mark's Hospital and to the German Dispensary, etc., New York City. In one very handsome octavo volume of about 700 pages, illustrated by numerous wood-cuts and colored plates. Prices: Cloth, $4.00 net; Sheep, $5.00 net.

A PRACTICAL work on gynecology for the use of students and practitioners, written in a terse and concise manner. The importance of a thorough knowledge of the anatomy of the female pelvic organs has been fully recognized by the author, and considerable space has been devoted to the subject. The chapters on Operations and on Treatment are thoroughly modern, and are based upon the large hospital and private practice of the author. The text is elucidated by a large number of illustrations and colored plates, many of them being original, and forming a complete atlas for studying *embryology* and the *anatomy* of the *female genitalia*, besides exemplifying, whenever needed, morbid conditions, instruments, apparatus, and operations.

EXCERPT OF CONTENTS.

Development of the Female Genitals.—Anatomy of the Female Pelvic Organs.—Physiology.—Puberty.—Menstruation and Ovulation.—Copulation.—Fecundation.—The Climacteric.—Etiology in General.—Examinations in General.—Treatment in General—Abnormal Menstruation and Metrorrhagia.—Leucorrhea.—Diseases of the Vulva.—Diseases of the Perineum.—Diseases of the Vagina.—Diseases of the Uterus.—Diseases of the Fallopian Tubes.—Diseases of the Ovaries.—Diseases of the Pelvis.—Sterility.

The reception accorded to this work has been most flattering. In the short period which has elapsed since its issue it has been adopted and recommended as a text-book by more than 60 of the Medical Schools and Universities of the United States and Canada.

"One of the best text-books for students and practitioners which has been published in the English language; it is condensed, clear, and comprehensive. The profound learning and great clinical experience of the distinguished author find expression in this book in a most attractive and instructive form. Young practitioners, to whom experienced consultants may not be available, will find in this book invaluable counsel and help."

THAD. A. REAMY, M. D., LL.D.,

Professor of Clinical Gynecology, Medical College of Ohio; Gynecologist to the Good Samaritan and Cincinnati Hospitals.

Practical, Exhaustive, Authoritative.

SAUNDERS'

NEW AID SERIES OF MANUALS

FOR

Students and Practitioners.

MR. SAUNDERS is pleased to announce as in *active preparation* his **NEW AID SERIES OF MANUALS for Students and Practitioners.** As publisher of the STANDARD SERIES OF QUESTION COMPENDS, and through intimate relations with leading members of the medical profession, Mr. Saunders has been enabled to study progressively the essential *desiderata* in practical "self-helps" for students and physicians.

This study has manifested that, while the published "Question Compends" earn the highest appreciation of students, whom they serve in reviewing their studies preparatory to examination, there is special need of thoroughly reliable handbooks on the leading branches of Medicine and Surgery, each subject being compactly and authoritatively written, and exhaustive in detail, without the introduction of *cases* and foreign subject-matter which so largely expand ordinary text-books.

The Saunders Aid Series will not merely be condensations from present literature, but will be ably written by well-known authors and practitioners, most of them being teachers in representative American Colleges. This *new series*, therefore, will form an admirable collection of advanced lectures, which will be invaluable aids to students in reading and in comprehending the contents of "recommended" works.

Each Manual will further be distinguished by the beauty of the *new* type; by the quality of the paper and printing; by the copious use of illustrations; by the attractive binding in cloth; **and by the extremely low price, which will uniformly be $1.25 per volume.**

Saunders' New Aid Series of Manuals.

A MANUAL OF PHYSIOLOGY. By JOSEPH H. RAYMOND, A. M., M.D., Professor of Physiology and Hygiene and Lecturer on Gynecology in the Long Island College Hospital; Director of Physiology in the Hoagland Laboratory; formerly Lecturer on Physiology and Hygiene in the Brooklyn Normal School for Physical Education; Ex-Vice-President of the American Public Health Association; Ex-Health Commissioner City of Brooklyn, etc. Illustrated. Price, Cloth, $1.25 net. (Just ready.)

In this manual the author has endeavored to put into a concrete and available form the results of twenty years' experience as a teacher of Physiology to medical students, and has produced a work for the student and practitioner, representing in a concise form the existing state of Physiology and its methods of investigation, based upon Comparative and Pathological Anatomy, Clinical Medicine, Physics, and Chemistry, as well as upon experimental research.

A MANUAL OF SURGERY, General and Operative. By JOHN CHALMERS DACOSTA, M. D., Demonstrator of Surgery, Jefferson Medical College, Philadelphia; Chief Assistant Surgeon, Jefferson Medical College Hospital; Surgical Registrar, Philadelphia Hospital, etc. One very handsome volume of over 700 pages, with a large number of illustrations. (Double number.) Price, Cloth, $2.50 net.

A new manual of the Principles and Practice of Surgery, intended to meet the demands of students and working practitioners for a medium-sized work which will embody all the newer methods of procedure detailed in the larger text-books. The work has been written in a concise, practical manner, and especial attention has been given to the most recent methods of treatment. Illustrations are freely used to elucidate the text.

A MANUAL OF OBSTETRICS. By W. A. NEWMAN DORLAND, M. D., Demonstrator of Obstetrics, University of Pennsylvania; Chief of Gynecological Dispensary, Pennsylvania Hospital; Member of Philadelphia Obstetrical Society, etc. Profusely illustrated. Price, Cloth, $1.25 net. (Preparing.)

This work, which is thoroughly practical in its teachings, is intended, as its title implies, to be a working text-book for the student and of value to the practitioner as a convenient handbook of reference. Although concisely written, nothing of importance is omitted that will give a clear and succinct knowledge of the subject as it stands to-day. Illustrations are freely used throughout the text.

Saunders' New Aid Series of Manuals.

DOSE-BOOK AND MANUAL OF PRESCRIPTION-WRITING. By E. Q. THORNTON, M. D., Demonstrator of Therapeutics, Jefferson Medical College, Philadelphia. Illustrated. Price, Cloth, $1.25 net.

But little attention is generally given, in works on Materia Medica and Therapeutics, to the methods of combining remedies in the form of prescriptions, and this manual has been written especially for students in the hope that it may serve to give a thorough and comprehensive knowledge of the subject.

The work, which is based upon the last (1890) edition of the *Pharmacopœia*, fully covers the subjects of Weights and Measures, Prescriptions (form of writing, general directions to pharmacist, grammatical construction, etc.), Dosage, Incompatibles, Poisons, etc.

MEDICAL JURISPRUDENCE AND TOXICOLOGY. By HENRY C. CHAPMAN, M. D., Professor of Institutes of Medicine and Medical Jurisprudence in the Jefferson Medical College of Philadelphia; Member of the College of Physicians of Philadelphia, of the Academy of Natural Sciences of Philadelphia, of the American Philosophical Society, and of the Zoological Society of Philadelphia. 232 pages, with 36 illustrations, some of which are in colors. Price, $1.25 net.

For many years there has been a demand from members of the medical and legal professions for a medium-sized work on this most important branch of medicine. The necessarily proscribed limits of the work permit the consideration only of those parts of this extensive subject which the experience of the author as coroner's physician of the city of Philadelphia for a period of six years leads him to regard as the most material for practical purposes.

Particular attention is drawn to the illustrations, many being produced in colors, thus conveying to the layman a far clearer idea of the more intricate cases.

"The salient points are clearly defined, and ascertained facts are laid down with a clearness that is unequivocal."—*St. Louis Medical and Surgical Journal.*

"The presentation is always thorough, the text is liberally interspersed with illustrations, and the style of the author is at once pleasing and interesting."—*Therapeutic Gazette.*

"One that is not overloaded with an unnecessary detail of a large amount of literature on the subject, requiring hours of research for the essential points in the decision of a question; that contains the most lucid symptomatology of questionable conditions, tests of poisons, and the readiest means of making them—such is the new book before us."—*The Sanitarian.*

A GUIDE TO THE BACTERIOLOGICAL LABORATORY. By LANGDON FROTHINGHAM, M. D. Illustrated. (In preparation.)

The technical methods involved in bacteria-culture, methods of staining, and microscopical study are fully described and arranged as simply and concisely as possible. The book is especially intended for use in laboratory work.

NURSING: ITS PRINCIPLES AND PRACTICE. By ISABEL ADAMS HAMPTON, Graduate of the New York Training School for Nurses attached to Bellevue Hospital; Superintendent of Nurses and Principal of the Training School for Nurses, Johns Hopkins Hospital, Baltimore, Md.; late Superintendent of Nurses, Illinois Training School for Nurses, Chicago, Ill. In one very handsome 12mo volume of 484 pages, profusely illustrated. Price, Cloth, $2.00 net.

This entirely new work on the important subject of nursing is at once comprehensive and systematic. It is written in a clear, accurate, and readable style, suitable alike to the student and the lay reader. Such a work has long been a desideratum with those intrusted with the management of hospitals and the instruction of nurses in training schools. It is also of especial value to the graduated nurse who desires to acquire a practical working knowledge of the care of the sick and the hygiene of the sick-room.

The author, who has had considerable experience as superintendent of training schools for nurses and hospital management, brings to her task a mind thoroughly equipped to make the subject attractive as well as scientific and instructive.

Thoroughly attested and approved processes in practical nursing only have been given, particularly in antiseptic surgery, and the minutest details regarding the nurse's technique have been explained.

Illustrations to elucidate the text have been used freely throughout the book, and they will be found of material help in showing the forms of modern appliances for the hospital ward and sick-room, the registration of temperature, daily records, etc.

METHODS OF PREVENTING AND CORRECTING DEFORMITIES OF THE BONES AND JOINTS: A Handbook of Practical Orthopedic Surgery. By H. AUGUSTUS WILSON, M. D, Professor of General and Orthopedic Surgery, Philadelphia Polyclinic; Clinical Professor of Orthopedic Surgery, Jefferson Medical College, Philadelphia, etc. (In preparation.)

The aim of the author is to provide a book of moderate size, containing comprehensive details that will enable general practitioners to understand thoroughly the mechanical features of the many forms of congenital and acquired deformities of the bones and joints.

The mechanical functions that are impaired will be considered first as to prevention as of primary importance, and following this will be described the methods of correction that have been proved practical by the author. Operative procedures will be considered from a mechanical as well as a surgical standpoint. Prominence will be given to the mechanical requirements for braces and artificial limbs, etc., with description of the methods for constructing the simplest forms, whether made of plaster of Paris, felt, leather, paper, steel, or other materials, together with the methods of readjustment to suit the changes occurring during the progress of the case. A very large number of original illustrations will be used.

AN OPERATION BLANK, with Lists of Instruments, etc. required in Various Operations. Prepared by W. W. KEEN, M. D., LL.D., Professor of Principles of Surgery in the Jefferson Medical College, Philadelphia. Price per Pad, containing Blanks for fifty operations, 50 cents net.

A convenient blank, suitable for all operations, giving complete instructions regarding necessary preparation of patient, etc., with a full list of dressings and medicines to be employed.

At the back of pad is a list of instruments used—viz. general instruments, etc., required for all operations; and special instruments for surgery of the brain and spine, mouth and throat, abdomen, rectum, male and female genito-urinary organs, the bones, etc.

The whole forming a neat pad, arranged for hanging on the wall of a surgeon's office or in the hospital operating-room.

"Will serve a useful purpose for the surgeon in reminding him of the details of preparation for the patient and the room as well as for the instruments, dressings, and antiseptics needed"—*New York Medical Record*

"Covers about all that can be needed in any operation."—*American Lancet.*

"The plan is a capital one."—*Boston Medical and Surgical Journal.*

ESSENTIALS OF ANATOMY AND MANUAL OF PRACTICAL DISSECTION, containing "Hints on Dissection." By CHARLES B. NANCREDE, M. D., Professor of Surgery and Clinical Surgery in the University of Michigan, Ann Arbor; Corresponding Member of the Royal Academy of Medicine, Rome, Italy; late Surgeon Jefferson Medical College, etc. Fourth and revised edition. Post 8vo, over 500 pages, with handsome full-page lithographic plates in colors, and over 200 illustrations. Price: Extra Cloth or Oilcloth for the dissection-room, $2.00 net.

Neither pains nor expense has been spared to make this work the most exhaustive yet concise Student's Manual of Anatomy and Dissection ever published, either in America or in Europe.

The colored plates are designed to aid the student in dissecting the muscles, arteries, veins, and nerves. The wood-cuts have all been specially drawn and engraved, and an Appendix added containing 60 illustrations representing the structure of the entire human skeleton, the whole being based on the eleventh edition of Gray's *Anatomy*, and forming a handsome post 8vo volume of over 500 pages.

"The plates are of more than ordinary excellence, and are of especial value to students in their work in the dissecting-room."—*Journal of American Medical Association.*

"Should be in the hands of every medical student."—*Cleveland Medical Gazette.*

"A concise and judicious work."—*Buffalo Medical and Surgical Journal.*

A MANUAL OF PRACTICE OF MEDICINE. By A. A. STEVENS, A. M., M. D., Instructor of Physical Diagnosis in the University of Pennsylvania, and Demonstrator of Pathology in the Woman's Medical College of Philadelphia. Specially intended for students preparing for graduation and hospital examinations, and includes the following sections: General Diseases, Diseases of the Digestive Organs, Diseases of the Respiratory System, Diseases of the Circulatory System, Diseases of the Nervous System, Diseases of the Blood, Diseases of the Kidneys, and Diseases of the Skin. Each section is prefaced by a chapter on General Symptomatology. Third edition. Post 8vo, 502 pages. Numerous illustrations and selected formulæ. Price, $2.50.

Contributions to the science of medicine have poured in so rapidly during the last quarter of a century that it is well-nigh impossible for the student, with the limited time at his disposal, to master elaborate treatises or to cull from them that knowledge which is absolutely essential. From an extended experience in teaching, the author has been enabled, by classification, to group allied symptoms, and by the judicious elimination of theories and redundant explanations to bring within a comparatively small compass a complete outline of the practice of medicine.

A SYLLABUS OF LECTURES ON THE PRACTICE OF SURGERY, arranged in conformity with The American Text-Book of Surgery. By NICHOLAS SENN, M. D., PH. D., Professor of Surgery in Rush Medical College, Chicago, and in the Chicago Polyclinic. Price, $2.00.

This, the latest work of its eminent author, himself one of the contributors to the "American Text-Book of Surgery," will prove of exceptional value to the advanced student who has adopted that work as his text-book. It is not only the syllabus of an unrivalled course of surgical practice, but it is also an epitome or supplement to the larger work.

SYLLABUS OF OBSTETRICAL LECTURES in the Medical Department, University of Pennsylvania. By RICHARD C. NORRIS, A. M., M. D., Demonstrator of Obstetrics in the University of Pennsylvania. Third edition, thoroughly revised and enlarged. Crown 8vo. Price, Cloth, interleaved for notes, $2.00 net.

"This work is so far superior to others on the same subject that we take pleasure in calling attention briefly to its excellent features. It covers the subject thoroughly, and will prove invaluable both to the student and the practitioner. The author has introduced a number of valuable hints which would only occur to one who was himself an experienced teacher of obstetrics. The subject-matter is clear, forcible, and modern. We are especially pleased with the portion devoted to the practical duties of the accoucheur, care of the child, etc. The paragraphs on antiseptics are admirable; there is no doubtful tone in the directions given. No details are regarded as unimportant; no minor matters omitted. We venture to say that even the old practitioner will find useful hints in this direction which he cannot afford to despise."—*New York Medical Record.*

OUTLINES OF OBSTETRICS: A Syllabus of Lectures Delivered at Long Island College Hospital. By CHARLES JEWETT, A. M., M. D., Professor of Obstetrics and Pediatrics in the College, and Obstetrician to the Hospital. Edited by HAROLD F. JEWETT, M. D. Post 8vo, 264 pages. Price, $2.00.

This book treats only of the general facts and principles of obstetrics: these are stated in concise terms and in a systematic and natural order of sequence, theoretical discussion being as far as possible avoided; the subject is thus presented in a form most easily grasped and remembered by the student. Special attention has been devoted to practical questions of diagnosis and treatment, and in general particular prominence is given to facts which the student most needs to know. The condensed form of statement and the orderly arrangement of topics adapt it to the wants of the busy practitioner as a means of refreshing his knowledge of the subject and as a handy manual for daily reference.

NOTES ON THE NEWER REMEDIES: their Therapeutic Applications and Modes of Administration. By DAVID CERNA, M. D., PH. D., Demonstrator of and Lecturer on Experimental Therapeutics in the University of Pennsylvania. Post-octavo, 175 pages. Price, $1.25.

The work takes up in alphabetical order all the newer remedies, giving their physical properties, solubility, therapeutic applications, administration, and chemical formula.

It thus forms a very valuable addition to the various works on therapeutics now in existence.

Chemists are so multiplying compounds, that, if each compound is to be thoroughly studied, investigations must be carried far enough to determine the practical importance of the new agents.

"Especially valuable because of its completeness, its accuracy, its systematic consideration of the properties and therapy of many remedies of which doctors generally know but little, expressed in a brief yet terse manner."—*Chicago Clinical Review.*

"A timely and needful book . . . . which physicians who avail themselves of the use of the newer remedies cannot afford to do without."—*The Sanitarian.*

LABORATORY EXERCISES IN BOTANY. By EDSON S. BASTIN, M. A., Professor of Materia Medica and Botany in the Philadelphia College of Pharmacy. With over 75 plates. (In preparation.)

This work is intended for the beginner and the advanced student, and it fully covers the structure of flowering plants, roots, ordinary stems, rhizomes, tubers, bulbs, leaves, flowers, fruits, and seeds. Particular attention is given to the gross and microscopical structure of plants, and to those used in medicine. Illustrations have freely been used to elucidate the text, and a complete index to facilitate reference has been added.

The folding charts which supplement the subjects will be found useful in connection with the study of the text.

SAUNDERS' POCKET MEDICAL LEXICON; or, Dictionary of Terms and Words used in Medicine and Surgery. By JOHN M. KEATING, M. D., editor of "Cyclopædia of Diseases of Children," etc.; author of the "New Pronouncing Dictionary of Medicine; and HENRY HAMILTON, author of "A New Translation of Virgil's Æneid into English Verse;" co-author of a "New Pronouncing Dictionary of Medicine." A new and revised edition. 32mo, 282 pages. Prices: Cloth, 75 cents; Leather Tucks, $1.00.

This new and comprehensive work of reference is the outcome of a demand for a more modern handbook of its class than those at present on the market, which, dating as they do from 1855 to 1884, are of but trifling use to the student by their not containing the hundreds of new words now used in current literature, especially those relating to Electricity and Bacteriology.

"Remarkably accurate in terminology, accentuation, and definition."—*Journal of American Medical Association.*

"Brief, yet complete . . . . it contains the very latest nomenclature in even the newest departments of medicine."—*New York Medical Record.*

SAUNDERS' POCKET MEDICAL FORMULARY. By WILLIAM M. POWELL, M. D., Attending Physician to the Mercer House for Invalid Women at Atlantic City. Containing 1750 Formulæ, selected from several hundred of the best-known authorities. Forming a handsome and convenient pocket companion of nearly 300 printed pages, with blank leaves for Additions; with an Appendix containing Posological Table, Formulæ and Doses for Hypodermatic Medication, Poisons and their Antidotes, Diameters of the Pemale Pelvis and Fœtal Head, Obstetrical Table, Diet List for Various Diseases, Materials and Drugs used in Antiseptic Surgery, Treatment of Asphyxia from Drowning, Surgical Remembrancer, Tables of Incompatibles, Eruptive Fevers, Weights and Measures, etc. Third edition, revised and greatly enlarged. Handsomely bound in morocco, with side index, wallet, and flap. Price, $1.75 net.

A concise, clear, and correct record of the many hundreds of famous formulæ which are found scattered through the works of the *most eminent physicians and surgeons* of the world. The work is helpful to the student and practitioner alike, as through it they become acquainted with numerous formulæ which are not found in text-books, but have been collected from among *the rising generation of the profession, college professors, and hospital physicians and surgeons.*

"This little book, that can be conveniently carried in the pocket, contains an immense amount of material. It is very useful, and as the name of the author of each prescription is given is unusually reliable."—*New York Medical Record.*

"Designed to be of immense help to the general practitioner in the exercise of his daily calling."—*Boston Medical and Surgical Journal.*

HOW TO EXAMINE FOR LIFE INSURANCE. By JOHN M. KEATING, M. D., Fellow of the College of Physicians and Surgeons of Philadelphia; Vice-President of the American Pædiatric Society; Ex-President of the Association of Life Insurance Medical Directors. Royal 8vo, 211 pages, with two large phototype illustrations, and a plate prepared by Dr. McClellan from special dissections; also, numerous cuts to elucidate the text. Second edition. Price, in Cloth, $2.00 net.

PART I., which has been carefully prepared from the best works on Physical Diagnosis, is a short and succinct account of the methods used to make examinations; a description of the normal condition and of the earliest evidences of disease.

PART II. contains the Instructions of twenty-four Life Insurance Companies to their medical examiners.

"This is by far the most useful book which has yet appeared on insurance examination, a subject of growing interest and importance. Not the least valuable portion of the volume is Part II., which consists of instructions issued to their examining physicians by twenty-four representative companies of this country. As the proofs of these instructions were corrected by the directors of the companies, they form the latest instructions obtainable. If for these alone, the book should be at the right hand of every physician interested in this special branch of medical science."—*The Medical News*, Philadelphia.

MANUAL OF MATERIA MEDICA AND THERAPEUTICS. By A. A. STEVENS, A. M., M. D., Instructor of Physical Diagnosis in the University of Pennsylvania, and Demonstrator of Pathology in the Woman's Medical College of Philadelphia. 435 pages. Price, Cloth, $2.25.

This wholly new volume, which is based on the 1890 edition of the *Pharmacopœia*, comprehends the following sections: Physiological Action of Drugs; Drugs; Remedial Measures other than Drugs; Applied Therapeutics; Incompatibility in Prescriptions; Table of Doses; Index of Drugs; and Index of Diseases; the treatment being elucidated by more than two hundred formulæ.

"The author is to be congratulated upon having presented the medical student with as accurate a manual of therapeutics as it is possible to prepare."—*Therapeutic Gazette*.

"Far superior to most of its class; in fact, it is very good. Moreover, the book is reliable and accurate."—*New York Medical Journal*.

"The author has faithfully presented modern therapeutics in a comprehensive work. . . . and it will be found a reliable guide."—*University Medical Magazine*.

"Will be of immense service to the busy practitioner."—*Medical Reporter* (Calcutta).

"Reliable and timely."—*North American Practitioner*.

"Concise, up to date, and withal comprehensive."—*Pacific Medical Journal*.

SAUNDERS' QUESTION COMPENDS.

Arranged in Question and Answer Form.

THE LATEST, CHEAPEST, and BEST ILLUSTRATED SERIES OF COMPENDS EVER ISSUED.

Now the Standard Authorities in Medical Literature

WITH

Students and Practitioners in every City of the United States and Canada.

THE REASON WHY.

They are the advance guard of "Student's Helps"—that DO HELP; they are the leaders in their special line, *well and authoritatively written by able men, who, as teachers in the large colleges, know exactly what is wanted by a student preparing for his examinations.* The judgment exercised in the selection of authors is fully demonstrated by their professional elevation. Chosen from the ranks of Demonstrators, Quiz-masters, and Assistants, most of them have become Professors and Lecturers in their respective colleges.

Each book is of convenient size (5 x 7 inches), containing on an average 250 pages, profusely illustrated, and elegantly printed in clear, readable type, on fine paper.

The entire series, numbering twenty-four subjects, has been kept thoroughly revised and enlarged when necessary, many of them being in their fourth and fifth editions.

TO SUM UP.

Although there are numerous other Quizzes, Manuals, Aids, etc. in the market, none of them approach the "Blue Series of Question Compends;" and the claim is made for the following points of excellence:

1. Professional distinction and reputation of authors.
2. Conciseness, clearness, and soundness of treatment.
3. Size of type and quality of paper and binding.

***** Any of these Compends will be mailed on receipt of price.**

1. **ESSENTIALS OF PHYSIOLOGY.** By H. A. HARE, M.D., Professor of Therapeutics and Materia Medica in the Jefferson Medical College of Philadelphia; Physician to St. Agnes' Hospital and to the Medical Dispensary of the Children's Hospital; Laureate of the Royal Academy of Medicine in Belgium, of the Medical Society of London, etc. Third edition, revised and enlarged by the addition of a series of handsome plate illustrations taken from the celebrated "Icones Nervorum Capitis" of Arnold. Crown 8vo, 230 pages, numerous illustrations. Price, Cloth, $1.00 net; interleaved for notes, $1.25 net.

"An exceedingly useful little compend. The author has done his work thoroughly and well. The plates of the cranial nerves from Arnold are superb."—*Journal of American Medical Association.*

2. **ESSENTIALS OF SURGERY,** containing also Venereal Diseases, Surgical Landmarks, Minor and Operative Surgery, and a Complete Description, together with full Illustrations, of the Handkerchief and Roller Bandages. By EDWARD MARTIN, A.M., M.D., Clinical Professor of Genito-Urinary Diseases, Instructor in Operative Surgery, and Lecturer on Minor Surgery, University of Pennsylvania; Surgeon to the Howard Hospital; Assistant Surgeon to the University Hospital, etc. Fifth edition. Crown 8vo, 334 pages, profusely illustrated. Considerably enlarged by an Appendix containing full directions and prescriptions for the preparation of the various materials used in Antiseptic Surgery; also several hundred recipes covering the medical treatment of surgical affections. Price, Cloth, $1.00; interleaved for notes, $1.25.

"Written to assist the student, it will be of undoubted value to the practitioner, containing as it does the essence of surgical work."—*Boston Medical and Surgical Journal.*

"Cleverly combines all the merits of condensation, while avoiding the errors of superficiality and inaccuracy."—*University Medical Magazine.*

3. **ESSENTIALS OF ANATOMY, including the Anatomy of the Viscera.** By CHARLES B. NANCREDE, M.D., Professor of Surgery and of Clinical Surgery in the University of Michigan, Ann Arbor; Corresponding Member of the Royal Academy of Medicine, Rome, Italy; late Surgeon to the Jefferson Medical College, etc. Fifth edition. Crown 8vo, 380 pages, 180 illustrations. Enlarged by an Appendix containing over sixty illustrations of the Osteology of the Human Body. The whole based upon the last (eleventh) edition of Gray's *Anatomy*. Price, Cloth, $1.00; interleaved for notes, $1.25.

"Truly such a book as no student can afford to be without."—*American Practitioner and News.*

"The questions have been wisely selected and the answers accurately and concisely given."—*University Medical Magazine.*

4. **ESSENTIALS OF MEDICAL CHEMISTRY, ORGANIC AND INORGANIC,** containing also Questions on Medical Physics, Chemical Physiology, Analytical Processes, Urinalysis, and Toxicology. By LAWRENCE WOLFF, M D., Demonstrator of Chemistry, Jefferson Medical College; Visiting Physician to the German Hospital of Philadelphia; Member of Philadelphia College of Pharmacy, etc. Fourth and revised edition, with an Appendix. Crown 8vo, 212 pages. Price, Cloth, $1.00; interleaved for notes, $1.25.

"The scope of this work is certainly equal to that of the best course of lectures on Medical Chemistry."—*Pharmaceutical Era.*

"We could wish that more books like this would be written, in order that medical students might thus early become interested in what is often a difficult and uninteresting branch of medical study."—*Medical and Surgical Reporter.*

5. **ESSENTIALS OF OBSTETRICS.** By W. EASTERLY ASHTON, M. D., Professor of Gynecology in the Medico-Chirurgical College of Philadelphia; Obstetrician to the Philadelphia Hospital. Third edition, thoroughly revised and enlarged. Crown 8vo, 244 pages, 75 illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

"An excellent little volume containing correct and practical knowledge. An admirable compend, and the best condensation we have seen."—*Southern Practitioner.*

"Of extreme value to students, and an excellent little book to freshen up the memory of the practitioner."—*Chicago Medical Times.*

6. **ESSENTIALS OF PATHOLOGY AND MORBID ANATOMY.** By C. E. ARMAND SEMPLE, B. A., M. B., Cantab. L. S. A., M. R. C. P. Lond., Physician to the Northeastern Hospital for Children, Hackney; Professor of Vocal and Aural Physiology and Examiner in Acoustics at Trinity College, London, etc. Crown 8vo, 174 pages, illustrated. Sixth thousand. Price, Cloth, $1.00; interleaved for notes, $1.25.

"A valuable little volume—truly a *multum in parvo.*"—*Cincinnati Medical News.*

"The volume is very comprehensive, covering the entire field of pathology."—*St. Joseph Medical Herald.*

7. **ESSENTIALS OF MATERIA MEDICA, THERAPEUTICS, AND PRESCRIPTION-WRITING.** By HENRY MORRIS, M. D., late Demonstrator, Jefferson Medical College; Fellow of the College of Physicians, Philadelphia; co-editor Biddle's Materia Medica; Visiting Physician to St. Joseph's Hospital, etc. Fourth edition. Crown 8vo, 250 pages. Price, Cloth, $1.00; interleaved for notes, $1.25.

"One of the best compends in this series. Concise, pithy, and clear, well suited to the purpose for which it is prepared."—*Medical and Surgical Reporter.*

"The subjects are treated in such a unique and attractive manner that they cannot fail to impress the mind and instruct in a lasting manner."—*Buffalo Medical and Surgical Journal.*

8, 9. **ESSENTIALS OF PRACTICE OF MEDICINE.** By HENRY MORRIS, M. D., author of "Essentials of Materia Medica," etc., with an Appendix on the Clinical and Microscopical Examination of Urine, by LAWRENCE WOLFF, M. D., author of "Essentials of Medical Chemistry," etc. Colored (Vogel) urine scale and numerous fine illustrations. Third edition, enlarged by some three hundred essential formulæ, selected from the writings of the most eminent authorities of the medical profession, collected and arranged by WILLIAM M. POWELL, M. D., author of "Essentials of Diseases of Children." Crown 8vo, 460 pages. Price, Cloth, $2.00.

"The teaching is sound, the presentation graphic, matter as full as might be desired, and the style attractive."—*American Practitioner and News.*

"A first-class practice of medicine boiled down, and giving the real essentials in as few words as is consistent with a thorough understanding of the subject."—*Medical Brief.*

"Especially full, and an excellent illustration of what the best of the compends can be made to be."—*Gaillard's Medical Journal.*

10. **ESSENTIALS OF GYNÆCOLOGY.** By EDWIN B. CRAGIN, M. D., Attending Gynæcologist, Roosevelt Hospital, Out-Patients' Department; Assistant Surgeon, New York Cancer Hospital, etc. Fourth edition, revised. Crown 8vo, 198 pages, 62 fine illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

"This is a most excellent addition to this series of question compends. The style is concise, and at the same time the sentences are well rounded. This renders the book far more easy to read than most compends, and adds distinctly to its value."—*Medical and Surgical Reporter.*

"Useful not only to the student who is barely at the threshold of professional life, but to the busy practitioner as well."—*New York Medical Journal.*

11. **ESSENTIALS OF DISEASES OF THE SKIN.** By HENRY W. STELWAGON, M. D., Clinical Lecturer on Dermatology in the Jefferson Medical College, Philadelphia; Physician to the Skin Service of the Northern Dispensary; Dermatologist to Philadelphia Hospital; Physician to Skin Department of the Howard Hospital; Clinical Professor of Dermatology in the Woman's Medical College, Philadelphia, etc. Third edition. Crown 8vo, 270 pages, 86 illustrations, many of which are original. Price, Cloth, $1.00; interleaved for notes, $1.25 net.

"An immense amount of literature has been gone over and judiciously condensed by the writer's skill and experience."—*New York Medical Record.*

"The book admirably answers the purpose for which it is written. The experience of the reviewer has taught him that just such a book is needed."—*New York Medical Journal.*

12. **ESSENTIALS OF MINOR SURGERY, BANDAGING, AND VENEREAL DISEASES.** By EDWARD MARTIN, A. M., M. D., author of "Essentials of Surgery," etc. Second edition. Crown 8vo, thoroughly revised and enlarged, 78 illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

"Characterized by the same literary excellence that has distinguished previous numbers of this series of compends."—*American Practitioner and News.*

"The best condensation of the subjects of which it treats yet placed before the profession."—*Medical News*, Philadelphia.

"A capital little book. The illustrations are remarkably clear and intelligible."—*Australian Medical Gazette.*

"We have nothing but praise for the subject-matter of this book."—*Bristol Medico-Chirurgical Journal.*

13. **ESSENTIALS OF LEGAL MEDICINE, TOXICOLOGY, AND HYGIENE.** By C. E. ARMAND SEMPLE, M. D., author of "Essentials of Pathology and Morbid Anatomy." Crown 8vo, 212 pages, 130 illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

"The leading points, the essentials of this too much neglected portion of medical science, are here summed up systematically and clearly."—*Southern Practitioner.*

"But for the author's judicious condensation of facts, the information it contains would be sufficient to fill an ordinary octavo volume."—*College and Clinical Record.*

14. **ESSENTIALS OF REFRACTION AND DISEASES OF THE EYE.** By EDWARD JACKSON, A. M., M. D., Professor of Diseases of the Eye in the Philadelphia Polyclinic and College for Graduates in Medicine; Member of the American Ophthalmological Society; Fellow of the College of Physicians of Philadelphia; Fellow of the American Academy of Medicine, etc.; and **ESSENTIALS OF DISEASES OF THE NOSE AND THROAT.** By E. BALDWIN GLEASON, S. B., M. D., Clinical Professor of Otology, Medico-Chirurgical College, Philadelphia; Surgeon in charge of the Nose, Throat, and Ear Department of the Northern Dispensary of Philadelphia; formerly Assistant in the Nose and Throat Dispensary of the Hospital of the University of Pennsylvania, and Assistant in the Nose and Throat Department of the Union Dispensary, etc. Two volumes in one. Second edition. Crown 8vo, 294 pages, 124 illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

"A valuable book to the beginner in these branches, to the student, to the busy practitioner, and as an adjunct to more thorough reading. The authors are capable men, and as successful teachers, know what a student most needs."—*New York Medical Record.*

"Very valuable, since in both sections is given about all that a candidate for examination is required to know."—*Medical Times and Hospital Gazette.*

15. **ESSENTIALS OF DISEASES OF CHILDREN.** By WILLIAM M. POWELL, M. D., Attending Physician to the Mercer House for Invalid Women at Atlantic City, N. J.; late Physician to the Clinic for the Diseases of Children in the Hospital of the University of Pennsylvania and St. Clement's Hospital; Instructor in Physical Diagnosis in the Medical Department of the University of Pennsylvania. Crown 8vo, 216 pages. Price, Cloth, $1.00; interleaved for notes, $1.25.

"This work is gotten up in the clear and attractive style that characterizes the Saunders Series. It contains in appropriate form the gist of all the best works in the department to which it relates."—*American Practitioner and News.*

"The book contains a series of important questions and answers, which the student will find of great utility in the examination of children."—*Annals of Gynæcology.*

16. **ESSENTIALS OF EXAMINATION OF URINE.** By LAWRENCE WOLFF, M. D., author of "Essentials of Medical Chemistry," etc. Colored (Vogel) urine scale and numerous illustrations. Crown 8vo. Price, Cloth, 75 cents.

"A little work of decided value."—*University Medical Magazine.*

"A good manual for students, well written, and answers, categorically, many questions beginners are sure to ask."—*New York Medical Record.*

"The questions have been well chosen, and the answers are clear and brief. The book cannot fail to be useful to students."—*Medical and Surgical Reporter.*

17. **ESSENTIALS OF DIAGNOSIS.** By SOLOMON SOLIS-COHEN, M. D., Professor of Clinical Medicine and Applied Therapeutics in the Philadelphia Polyclinic, and AUGUSTUS A. ESHNER, M. D., Instructor in Clinical Medicine, Jefferson Medical College, Philadelphia. Crown 8vo, 382 pages, 55 illustrations, some of which are colored, and a frontispiece. Price, $1.50 net.

"A good book for the student, properly written from their standpoint, and confines itself well to its text."—*New York Medical Record.*

"Concise in the treatment of the subject, terse in expression of fact. . . . The work is reliable, and represents the accepted views of clinicians of to-day."—*American Journal of Medical Sciences.*

"The subjects are explained in a few well-selected words, and the required ground has been thoroughly gone over."—*International Medical Magazine.*

18. **ESSENTIALS OF PRACTICE OF PHARMACY.** By LUCIUS E. SAYRE, M. D., Professor of Pharmacy and Materia Medica in the University of Kansas. Second edition, revised and enlarged. Crown 8vo, 200 pages. Price, Cloth, $1.00; interleaved for notes, $1.25.

"Covers a great deal of ground in small compass. The matter is well digested and arranged. The research questions are a valuable feature of the book."—*Albany Medical Annals.*

"The best quiz on Pharmacy we have yet examined."—*National Drug Register.*

"The veteran pharmacist can peruse it with pleasure, because it emphasizes his grasp upon knowledge already gleaned."—*Western Drug Record.*

20. **ESSENTIALS OF BACTERIOLOGY: A Concise and Systematic Introduction to the Study of Micro-organisms.** By M. V. BALL, M. D., Assistant in Microscopy, Niagara University, Buffalo, N. Y.; late Resident Physician, German Hospital, Philadelphia, etc. Second edition, revised. Crown 8vo, 200 pages, 81 illustrations, some in colors, and 5 plates. Price, Cloth, $1.00; interleaved for notes, $1.25.

"The amount of material condensed in this little book is so great, and so accurate are the formulæ and methods, that it will be found useful as a laboratory handbook."—*Medical News.*

"Bacteriology is the keynote of future medicine, and every physician who expects success must familiarize himself with a knowledge of germ-life—the agents of disease. This little book, with its beautiful illustrations, will give the students, in brief, the results of years of study and research unaided."—*Pacific Record of Medicine and Surgery.*

"Thoroughly practical, very concise, clear, well-written, and sufficiently illustrated. . . . The best book of the kind in the English language."—*Medical and Surgical Reporter.*

21. **ESSENTIALS OF NERVOUS DISEASES AND INSANITY, their Symptoms and Treatment.** By JOHN C. SHAW, M. D., Clinical Professor of Diseases of the Mind and Nervous System, Long Island College Hospital Medical School; Consulting Neurologist to St. Catherine's Hospital and to the Long Island College Hospital; formerly Medical Superintendent King's County Insane Asylum. Second edition, Crown 8vo, 186 pages, 48 original illustrations, mostly selected from the Author's private practice. Price, Cloth, $1.00; interleaved for notes, $1.25.

"Clearly and intelligently written."—*Boston Medical and Surgical Journal.*

"A valuable addition to this series of compends, and one that cannot fail to be appreciated by all physicians and students."—*Medical Brief.*

"Dr. Shaw's Primer is excellent. The engravings are well executed and very interesting."—*Medical Times and Register.*

"Written with great clearness, devoid of verbosity, it encompasses in a brief space a vast amount of valuable information."—*Pacific Medical Record.*

22. **ESSENTIALS OF PHYSICS.** By FRED J. BROCKWAY, M. D., Assistant Demonstrator of Anatomy in the College of Physicians and Surgeons, New York. Second edition. Crown 8vo, 320 pages, 155 fine illustrations. Price, Cloth, $1.00 net; interleaved for notes, $1.25 net.

"The publisher has again shown himself as fortunate in his editor as he ever has been in the attractive style and make-up of his compends."—*American Practitioner and News.*

"Contains all that one need know of the subject, is well written, and is copiously illustrated."—*New York Medical Record.*

"The author has dealt with the subject in a manner that will make the theme not only comparatively easy, but also of interest."—*Medical News*, Philadelphia.

"Deserving of close investigation at the hands of students and physicians."—*American Gynecological Journal.*

23. **ESSENTIALS OF MEDICAL ELECTRICITY.** By D. D. STEWART, M. D., Demonstrator of Diseases of the Nervous System and Chief of the Neurological Clinic in the Jefferson Medical College; Physician to St. Mary's Hospital and to St. Christopher's Hospital for Children, etc.; and E. S. LAWRANCE, M. D., Chief of the Electrical Clinic, and Assistant Demonstrator of Diseases of the Nervous System in the Jefferson Medical College, etc. Crown 8vo, 148 pages, 65 illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

"Clearly written, and affords a safe guide to the beginner in this subject."—*Boston Medical and Surgical Journal.*

"The subject is presented in a lucid and pleasing manner."—*New York Medical Record.*

"A little work on an important subject, which will prove of great value to medical students and trained nurses who wish to study the scientific as well as the practical points of electricity."—*The Hospital*, London.

"The selection and arrangement of material are done in a skilful manner. It gives, in a condensed form, the principles and science of electricity and their application in the practice of medicine."—*Annals of Surgery.*

"The compilation is a good one, and will be found useful both to students and to men in practice."—*New Zealand Medical Journal.*

24. **ESSENTIALS OF DISEASES OF THE EAR.** By E. B. GLEASON, S. B., M. D., Clinical Professor of Otology, Medico-Chirurgical College, Philadelphia; Surgeon in Charge of the Nose, Throat, and Ear Department of the Northern Dispensary of Philadelphia; formerly Assistant in the Nose and Throat Dispensary of the Hospital of the University of Pennsylvania, and Assistant in the Nose and Throat Department of the Union Dispensary. 89 illustrations. Price, Cloth, $1.00; interleaved for notes, $1.25.

This latest addition to the Saunders Compend Series accurately represents the modern aspect of otological science. The effort has been made to state the Essentials of Otology concisely, without sacrificing accuracy to brevity, and the book, while small in compass, is logically and capably written; it comprises upward of 150 pages, with 89 illustrations, most of which are from original sources.